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Evaluation and Ranking of Geothermal Resources for Electrical Generation or Electrical Offset in Idaho, Montana, Oregon and Washington

by

R. G. Bloomquist, G. L. Black, D. S. Parker,
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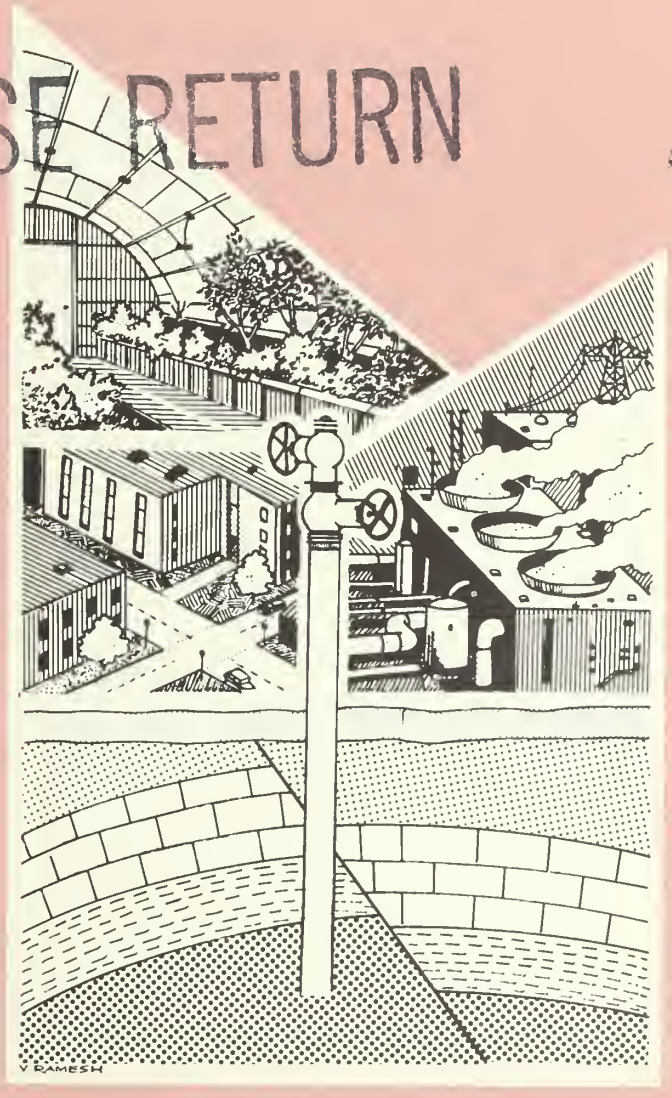

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Evaluation and Ranking of Geothermal Resources for Electrical Generation or Electrical Offset in Idaho, Montana, Oregon and Washington

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Washington State Energy Office
in cooperation with:

Idaho Department of Water Resources
Montana Department of Natural Resources & Conservation
Oregon Department of Energy
Oregon Department of Geology and Mineral Industries

Principal Investigator

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June, 1985

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CONVERSION FACTORS

Metric/English Conversions

1 m^3	=	35.3 ft^3 = 264 gals
1 meter	=	3.281 ft
1 kilogram	=	2.2 lb.
1 liter	=	0.264 gal. = 0.0353 ft^3
1 liter/sec = .001 m^3/sec	=	15.8 gpm
1 liter/min	=	.263 gpm
1 joule	=	0.000948 Btu
1°C	=	(°F - 32°) x 5/9
1 m^2	=	10.76 ft^2
1 kilometer	=	.62 miles
1 hectare	=	2.47 acres

Nominal Fuel Heating Values

1 cubic foot natural gas	=	1,000 Btu
1 pound bituminous coal	=	12,500 Btu
1 gal. #2 fuel oil	=	1.42×10^5 Btu
1 Therm	=	10^5 Btu
1 barrel crude oil	=	5.6 million Btu
1 kWh	=	3,413 Btu
1 ton of refrigeration	=	12,000 Btu

Energy Unit Conversion Chart
(100% Efficiency)

British Thermal Units (Btu)	Cubic Feet Natural GAs (CF)	Kilowatt Hours Electricity (kWh)	Barrels of Oil (bbl)	Short Tons Bituminous Coal (T)	Tons of Refrigeration*
1	0.001	0.000293	---	---	---
1,000	1	0.293	0.00018	0.0004	.0833
3,413	3.41	1	0.00061	0.00014	.284
1 Million	1,000 (1 MCF)	293	0.18	0.04	83.3
3.41 Million	3,413	1,000 (1 MWh)	0.61	0.14	284
5.6 Million	5,600	1,640	1	0.22	466
25 Million	25,000	7,325	4.46	1	2,083
1 Quadrillion (Quad) (Q)	1 Trillion (1 TCF)	293 Billion	180 Million	40 Million	83.3 Billion

*Defined as the heat of fusion of one ton of water, equal to 288,000 Btus.

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CHAPTER 1

Introduction

INTRODUCTION

The commercial use of geothermal energy in the Pacific Northwest Region of Idaho, Montana, Oregon, and Washington began with the construction of the Warm Springs Heating District in Boise, Idaho, in the early 1890's. By 1910, a number of residences and business establishments in Klamath Falls, Oregon, were meeting their heating needs through geothermal energy. The resource, however, was considered more a novelty than a major energy resource even though geothermal waters were used at a number of locations in the region for space heating and balenological (therapeutic bathing) purposes.

Interest, however, began to increase during the 1960's with the first successful American test use of geothermal energy to produce electricity at The Geysers in northern California. Energy companies and utilities became interested in geothermal energy as an inexpensive way to produce electricity, and although there was very little information about the location and availability of geothermal resources, a search of existing literature produced references of hundreds of thermal and mineral springs in the western half of the country and information on widespread recent volcanism.

Interest in geothermal energy peaked in the early 1970's with the passage of the Geothermal Steam Act of 1970, the Arab oil embargo of 1972-74, the establishment of the federal geothermal leasing program in 1974, and the publishing by the United States Geological Survey of USGS Circular 726--Assessment of Geothermal Resources of the United States--in 1975.

By the mid-1970's, the United States Geological Survey (USGS) and the Energy Research and Development Administration (ERDA) had established a number of programs to assess the geothermal resources of the United States and to encourage development. The Federal Geothermal Energy Research, Development, and Demonstration Act, (Public Law 93-410) passed late in 1974, was critical to this effort. Public Law 93-410 provided the USGS, ERDA, and later the U.S. Department of Energy (USDOE) with the direction and authority to aggressively pursue geothermal exploration and development. It also established the Geothermal Loan Guarantee Program, the Program Research and Development Announcement (PRDA), the Program Opportunity Notice (PON), and the Industry Coupled Program. In addition to the above programs, which were aimed primarily at development of geothermal resources by private industry, a number of other programs were established by the USGS and ERDA/USDOE to actively involve state

agencies in assessment and development activities. Three of these programs had a significant impact upon geothermal exploration and development in the BPA four-state region. They were: the State Coupled Program which involved state geological surveys in resource assessments; the State Commercialization Program which focused the efforts of state energy offices upon promotion of a sound legal and institutional framework supportive of geothermal exploration and development; and the Technical Assistance Program which provided potential developers with engineering and economic assistance. These programs were instrumental in the development of geothermal projects in Boise, Idaho; Klamath Falls, Vale, and Lakeview, Oregon; and Ephrata and Yakima, Washington.

Interest in geothermal energy remained high through the late 1970's and early 1980's due to increasing oil prices and a second major oil shortage in 1979.

By 1981, however, major changes began to occur at the national level. Oil prices stabilized and a diminished emphasis was placed on renewable energy resources. Two new players entered the energy future of the BPA four-state region in 1981. The passage of the Pacific Northwest Electrical Power Planning and Conservation Act (P.L. 96-50) in December 1980, created the Pacific Northwest Power Planning Council, and also gave Bonneville Power Administration (BPA) new authority and responsibility for providing and regulating a majority of the region's electrical power supplies. Although the national emphasis on energy development was waning, a forecasted local electrical energy deficit and the provisions of the Pacific Northwest Electrical Power Planning and Conservation Act helped maintain a regional emphasis upon geothermal exploration and development.

The northwestern regional states began to work more closely with BPA and they submitted detailed suggestions for geothermal program implementation in the spring of 1981. These programs emphasized the need to accelerate exploration and development by state and federal agencies and economic support for industry involvement.

By late 1981, however, the local electrical energy picture seemed to change, and the forecasted deficit was replaced by a forecasted surplus. The need for accelerated exploration vanished as did the dream of many energy development companies that rising regional electrical prices would create a profitable market for geothermal energy. With the announced surplus, energy planners throughout the region returned to their drawing boards and focused attention on how to best determine resource potential, development potential, and costs; and what activities should be undertaken to ensure that cost-effective geothermal resources could be brought on-line to meet future demand.

At this time, the Bonneville Power Administration turned to the Washington State Energy Office (WSEO) and requested that WSEO coordinate a detailed regional geothermal assessment program to bring together expertise existing in state energy and resource offices in the northwest. The objective of this program was to consolidate and evaluate all geologic, environmental, and legal and institutional information in existing records and files, and to apply a uniform methodology to the evaluation and ranking of sites. This data base would allow the making of creditable forecasts of the supply of geothermal energy which could be available in the region over a 20 year planning horizon. The present report is the result of this request by BPA.

Various state agencies were assigned tasks according to their particular abilities to manage this data collection. The Oregon Department of Geology and Mineral Resources was assigned the lead to interpret geological data and to estimate resource potential. The Oregon Department of Energy was assigned the lead to analyze geothermal electrical generation, facility configurations, and cost estimates. The Idaho Department of Water Resources was requested to determine direct use scenarios and energy costs. The Montana Department of Natural Resources and Conservation was assigned the lead to develop a methodology for ranking both electrical and direct use sites. And the Washington State Energy Office assumed responsibility for coordinating the overall assessment program, and took the lead for the analysis of legal, institutional, and environmental concerns which impact the developability of geothermal resources for electrical generation and/or electrical offset.

To accomplish these tasks, the Four-State Assessment Team initially identified a total of 1,265 potential geothermal resource sites from existing literature. Site selection was based upon the presence of thermal and mineral springs or wells and/or areas of recent volcanic activity and high heat flow. The 1,265 sites were then screened (Chapter 2) to eliminate those which had little or no chance of development because of inadequacies of resource temperature, legal prohibitions against development, or inadequate heat demands within economical transmission distances of direct use resource sites. Of the original 1,265 sites, 250 sites were selected for detailed analysis.

A methodology to rank the sites by energy potential, degree of developability, and cost of energy was then developed. Ranking procedures were intended to compare sites relative to each other and to indicate which sites possessed **superior** developability, **average** developability, or **inferior** potential.

The Assessment Team determined that energy potential could best be estimated by a methodology established by the USGS for assessment of the geothermal potential in the United States and presented in USGS Circulars 726, 790, and 892 (see Chapter 3). A major advantage of adopting the basic USGS methodology is that it permits a direct comparison of USGS results with the Team analysis.

Resource developability was ranked by a method based on a weighted variable evaluation of resource favorability (see Chapter 6). This technique is an expansion of one developed by McClain in 1980, and it has been significantly modified to allow for the large uncertainties that surround geothermal resource assessment. The developability index uses the Delphi approach of "expert advice" from geologists, engineers, resource regulators, and city planners. At this point, a Technical Review Committee of invited representatives from regulatory agencies, utilities, energy companies, and engineering firms was enlisted to help create a developability index and to oversee the development of the ranking system.

Energy costs for electrical generation are based upon estimates by Bechtel National Inc. (see Chapter 8). Direct use costs are calculated by the computer program HEATPLAN, developed by Eliot Allen and Associates (see Chapter 9).

Finally, sites were ranked using an integration of values determined through the cost and developability analysis (see Chapter 10). A summary presentation of our ranking data occurs in Chapter 10.

This report is divided into two volumes. Volume one is an account of the methodology established for determining resource and energy potential, its developability, the costs of energy, site rankings, and conclusions and program recommendations. A comprehensive bibliography about the geologic characteristics, economics, engineering features, and potential applications of American geothermal energy appears at the conclusion of Volume one. Volume two includes the various computer programs used to derive the analyses, and the results of the analyses. An Executive Table of Contents, for easy reference, follows immediately.

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CHAPTER 2

Site Selection Criteria

2.0 SITE SELECTION CRITERIA

2.1 Introduction

A primary objective of the Pacific Northwest Regional Geothermal Assessment Study is to identify all geothermal sites listed in existing literature. A set of selection criteria has been established by the Four-State Assessment Team and the Technical Review Committee (TRC) of this study, to determine which sites were to be analyzed in detail. Geothermal resource site lists are separated into three major categories: 1) a comprehensive master list, 2) a list of sites eliminated from further study because economic, legal, or environmental constraints prevent their development, and 3) final site lists of electrical generation and direct utilization sites (**see Exhibit I at the back of Volume I**). This data forms a foundation from which the geothermal energy potential of the region can be estimated.

2.2 Selection Criteria

To realistically study geothermal sites of the Pacific Northwest, a set of selection criteria is necessary. A preliminary set of criteria was formulated by the four state team which consisted of:

I. Master List

- o All Geothermal Wells and Springs in the Four-State Region.

II. Screened List (i.e., sites which will not be given further consideration).

- o Sites in Legally-Designated Areas
- o Sites with Temperatures less than 10°C Above the Mean Ambient Air Temperature
- o Geothermal Resources Greater Than 8 km From a City or Town.

III. Final Site Lists

- o Electrical Generation Geothermal Resource Sites.
- o Direct Utilization Geothermal Resource Sites.

This preliminary criteria was then reviewed by the Technical Review Committee (TRC) composed of representatives utilities, federal regulatory agencies, consulting firms, state agencies, and private developers. (A list of

TRC members has been provided in the acknowledgements to this study.) A final list of selection criteria incorporating recommendations of the TRC was developed as follows:

I. Master List

- o All Geothermal Wells and Springs, or Areas of Recent Volcanic Activity and High Heat Flow.

II. Screened List (i.e., sites which will not be given further consideration)

- o Sites in Legally-Designated Areas.
- o Sites with Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites with Volcanics Older Than That of a Favorable Site.*
- o Sites with Temperatures less than 10°C Above the Mean Ambient Air Temperature.
- o Sites Failing the Population/Distance Requirement: (see Table 2.1)

III. Final Site Lists

- o Electrical Generation Sites
- o Direct Utilization Sites

*(See 2.3.2.2)

An important concern of the TRC was to ensure the evaluation of "blind" geothermal sites. Sites with recent (less than one million years old) volcanic activity, which do not have an associated surface manifestation (i.e., a hot spring) from which to calculate a geothermometer, are called "blind" sites. These sites may indicate cooling magma chambers at depth which may be associated with water-bearing rock. (Water and heat are the two basic requirements of an economic geothermal system.)

When site selection criteria were finally accepted, the time-consuming task of compiling lists of sites began. To do this most effectively, the members of the Four-State Assessment Team concentrated on available literature in their respective states. Although some recent information has been generated by federal agencies, most new data have been generated by the states as part of ongoing geothermal exploration programs. Access to this data base, and a pre-

existing knowledge of the geothermal resources of the states, enabled the four state study team to establish a comprehensive Master List.

2.3 Detailed Selection Criteria Description

All known potential geothermal sites were considered. A Master List which included thermal springs, mineral springs, and areas of recent volcanic activity provided a comprehensive data base. This list was screened to eliminate sites where development is prohibited by law, economics, or by limited resource information. After screens were applied, the remaining sites were separated into categories of electrical generation resource sites, direct utilization resource sites or, in some cases, both.

2.3.1 Master List Criteria

For the purpose of the Master List, geothermal sites are defined as any well or spring which exhibits a higher than normal groundwater temperature and/or higher than normal concentrations of minerals; or an area of recent volcanic activity with relatively high heat flow.

2.3.1.1 Thermal Wells and Springs

Thermal wells and springs have waters with measured temperatures above the mean annual ambient air temperature. Normal groundwater temperature usually is related to the mean annual ambient air temperature. Any water with a higher temperature may indicate the presence of a geothermal resource.

2.3.1.2 Mineral Waters

Unusually high concentrations of certain minerals in water may indicate geothermal activity in a reservoir at depth. An elevated temperature in a reservoir causes minerals of the host rock to go into solution until equilibrium is reached between the geothermal fluid and the rock. Equilibria are temperature dependent. The determination of a reservoir temperature from an analysis of chemical concentrations of such ions as Na-K-Ca and S_iO_2 is known as geothermometry (see 3.3.2.3). Any mineral water identified in the study region with a geothermometer of 90°C or greater is included on the Master List.

2.3.1.3. Volcanic Sites

Recent volcanic centers may indicate cooling magma chambers at depth. These chambers could serve as a heat source for a geothermal system. The recent (less than one million years old) volcanic centers in the BPA study region were included on the Master List.

2.3.2 Site Screens

2.3.2.1 Sites in Legally-Designated Areas

Many sites are located in areas where leasing for geothermal development is not permitted. The Geothermal Steam Act of 1970 states that leasing is not be permitted in National Parks, National Monuments, National Recreation Areas, fish hatcheries, identified wildlife areas, and lands selected by the Secretary of the Interior. The Act clearly precludes any development in these governmentally designated areas. Wilderness Areas are restricted from development because surface occupancy is not allowed. Sites located within these areas have been dropped from further consideration in this study.

2.3.2.2 Sites With Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites With Volcanics Older Than That of a Favorable Site

This screen concerns geothermal sites which have a "most likely" geothermometer (see 3.3.2.3) of less than 90°C, and areas of volcanic activity (older than 1 million years). This includes mineral springs, thermal springs, hot wells, and volcanic sites.

Volcanic sites are screened using a rock composition and age requirement (see Table 2.1).

TABLE 2.1 - Volcanics Screen

Rock Type	Age (10^3 Years)	
Basalt	Greater than	40
Andesite	Greater than	100
Rhyolite	Greater than	1,000

Resource sites which pass the first two screens qualify as electrical generation sites on the Final List. Potential direct utilization sites which lack a geothermometer or recent volcanic activity are dropped to the third screen as shown in Figure 2.1. A site that passes the first two screens, and is listed as an electrical generation site, may also be considered as a direct utilization site in the last two screens.

2.3.2.3 Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature

This screen is taken from methodology used by the U.S. Geological Survey to assess low temperature geothermal resources (Reed, 1982). Sites that have a measured temperature of less than 10°C above mean ambient air temperature, and do not meet the requirement of the 90°C geothermometer, are dropped from further consideration.

2.2.2.4 Sites Failing Population/Distance Requirements

Proximity to a populated, commercial center is an important criterion for direct utilization geothermal sites. To limit the number of geothermal wells or springs considered for use at a direct utilization site (see 2.3.3.2), a population/distance requirement reflecting economic constraints has been applied as the final screen for direct utilization sites. To illustrate this requirement, consider that a large city with a high concentrated heat load can economically deliver geothermal energy to the residents from a much longer distance than can a small town. Table 2.2 was used to limit the number of cities and towns to be analyzed in the assessment, to those which have the greatest potential for developing economical geothermal district heating systems.

TABLE 2.2 - Population/Distance Requirements

POPULATION	DISTANCE TO RESOURCE
1-100	On Site
101-1,000	Less Than 2 km
1,001-10,000	Less Than 10 km
10,001-100,000	Less Than 20 km
100,001 +	Less Than 40 km

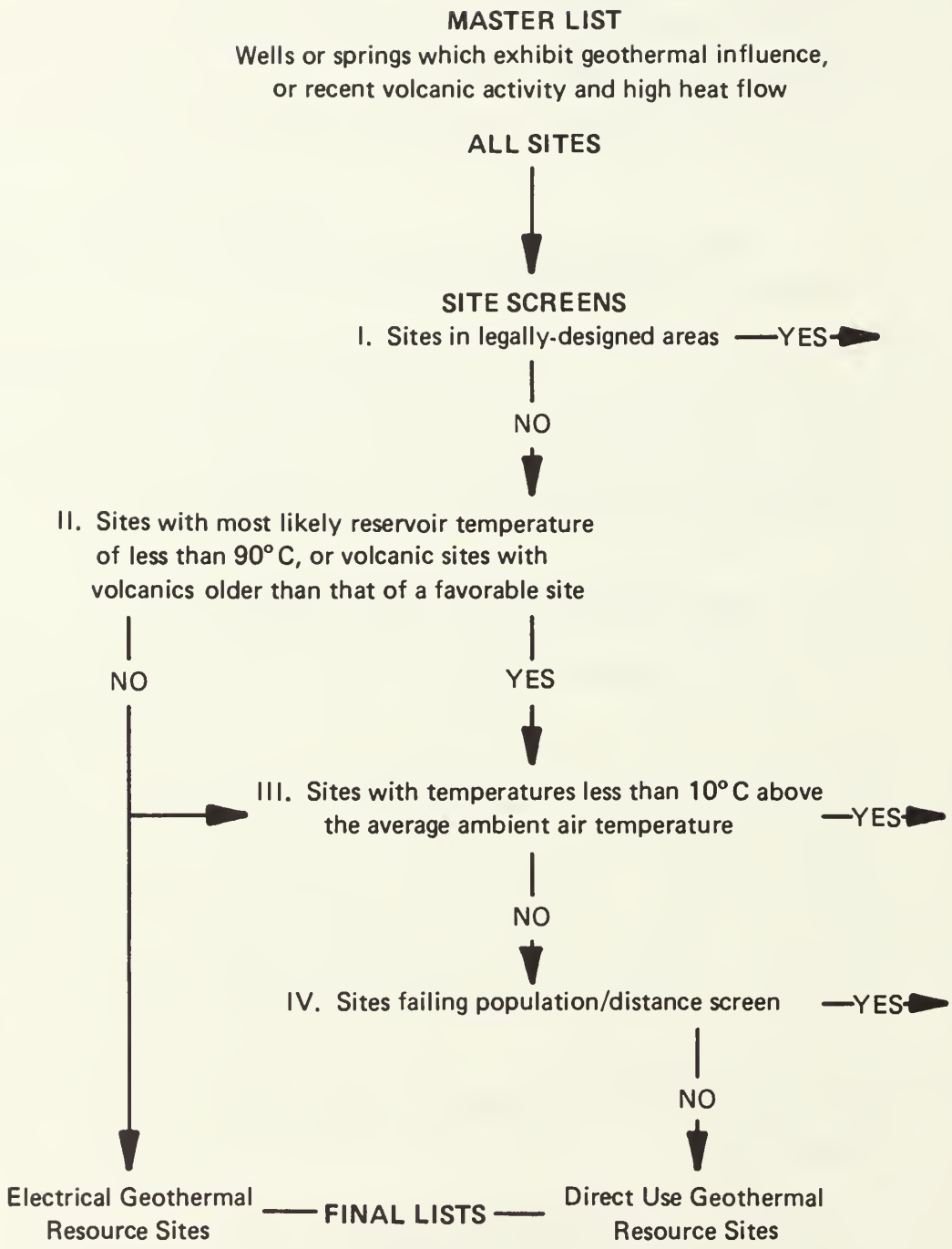

Figure 2.1 — Site selection criteria.

Economic evaluations of direct utilization sites are presented in Chapters 9 and 10, which concern Direct Utilization Site Analysis and Ranking Results.

2.3.3 Final Site Lists

The Final Site Lists tabulate electrical and direct utilization geothermal resource sites for each of the four states. These sites are evaluated in subsequent chapters for energy potential, electrical generation potential, offset potential, status of exploration, and ranked according to developability.

2.3.3.1 Electrical Generation Sites

Electrical generation sites on the Final Site Lists are wells or springs that have a 'most likely' reservoir temperature of 90°C or greater, and are not located in an area where leasing is prohibited. Areas of recent volcanic activity are also included. Table 2.1 displays the maximum ages considered for three common volcanic rocks which span the range of possible volcanic rock types.

2.3.3.2 Direct Utilization Sites

Direct utilization sites on the Final Site Lists are points of end use such as towns, cities, or other population centers. Wells or springs are the geothermal resources which are used by these sites. This list consolidates many wells of one area, given as sites in the Master List, into a more realistic assessment of resource utilization potential. These direct utilization sites are near a geothermal resource which is at least 10°C above the mean annual ambient air temperature and outside of a legally designated area.

2.4 Conclusion

A lack of data has been a major impediment to development of the site lists, particularly where electrical generation sites are concerned. With continued exploration efforts, many more sites can be expected to be added to the list. In the case of the direct utilization sites, nearly all resources identified are existing municipal wells and thermal springs. The direct utilization site list is more complete than the electrical generation site list because the geothermal resources are better known.

Table 2.3 gives the number of sites taken from various geothermal resource site lists. Complete lists of sites, state-by-state, are displayed in the accompanying Exhibit I.

TABLE 2.3 - Quantitative Site Selection Summary

Characteristic	Idaho	Montana	Oregon	Washington	Total
Master List (1)	441	66	247	511	1,265
Screens:					
Legally-Designated Areas	0	1	11	20	32
Reservoir Less Than 90°C & Old Volcanics	1	0	19	31	51
Less Than 10°C Above Mean Air Temperature	1	4	3	38	46
Population/Distance Requirements	274	27	128	253	682
Final Site Lists:					
Electric Generation Sites (2)	31	8	57	4	100
Direct Utilization Sites (3)	44	20	40	41	145

(1) All known/inferred sites - all temperatures.

(2) Reservoirs greater than 90°C or recent volcanics, screens I & II applied.

(3) Screens I, III, and IV applied.

CHAPTER 3

Resource Evaluation Methodology

3.0 RESOURCE EVALUATION METHODOLOGY

3.1 Introduction

The objective of the four-state study is to characterize the nature of geothermal resources within the states of the Pacific Northwest which comprise the Bonneville Power Administration's (BPA) service area. BPA requires this information to make credible forecasts of the supply of geothermal energy for electrical generation or electric load offset over a 20-year planning horizon, and to evaluate potential demonstration projects which may be submitted as a result of implementing the Regional Power Planning Council's 2-year action plan. Four tasks comprise the study:

(1) Characterization of electric generation resource sites (i.e., those sites with temperatures greater than 90°C).

(2) Characterization of direct utilization sites (i.e., those sites which can provide electric load offset).

(3) Review of federal, state, and local legal, institutional, and environmental requirements which impact resource development.

(4) Site ranking.

To characterize potential resources and to rank geothermal sites, it was decided to evaluate each site in Washington, Idaho, Oregon, and Montana according to:

(1) The magnitude of the resource at the site.

(2) The nature of the market that the site might serve.

(3) Any regulatory/environmental problems which might affect the development of the site.

The actual determination of what does or does not constitute a geothermal site is discussed in Chapter 2 of this report. This section is concerned with the methodology used to estimate the magnitude of the geothermal resource at a particular site.

In the discussion which follows, alternative methodologies for evaluating geothermal resources are briefly described, as are the criteria for selection of the methodology employed. A more detailed description of high temperature (greater than 90°C), and low temperature (less than 90°C) methods follows. A separate section is required for each temperature range because, although the basic methodology is the same for each, there are differences in detail between them. The discussion of high temperature methods includes a section on igneous-related systems. Because these resources typically do not have surface expressions (e.g., hot springs), they require special treatment. Finally, there is a section on geothermal resources in the Cascade Range of Oregon and Washington to illustrate the nature of the geothermal resource there, and the problems involved with evaluating it.

Resource assessment results are found in Appendices 1 and 2 and a summary of results is given in Exhibit II.

3.2 Alternative Resource Evaluation Methodologies

To assess the geothermal potential and useful lifetime of a specific geothermal site, reliable estimates must be made of the amount of heat contained in the reservoir, the rate at which it can be extracted, and the extent of hot water recharged into the system (Bodvarsson et al., 1981). Where abundant production well data are available for a specific site, it is relatively easy to develop these estimates, although it must be noted that truly accurate models (and hence optimum reservoir extraction rates, rates of recharge, and lifetimes) can be developed only after production has been monitored for a period of years.

Unfortunately, in the Pacific Northwest adequate production well data are nowhere available, except possibly for the low temperature systems of Boise, Idaho, and Klamath Falls, Oregon. In fact, production well data do not exist for the majority of sites listed in Exhibit I. The problem is actually one of estimating the magnitude of geothermal resources at a specific site in the absence of subsurface information.

Muffler and Cataldi (1978) have described four categories into which various assessment methodologies can be divided. These are:

(1) The method of surface heat flux.

(2) Planar fracture method.

(3) Volume methods.

(4) Methods of magmatic heat budget.

Each of these methods is briefly described along with its advantages, disadvantages, and possible applications in the Pacific Northwest. The following descriptions are, for the most part, taken from Muffler and Cataldi (1978).

3.2.1 Method of Thermal Heat Flux

The thermal heat flux method measures the amount of thermal energy transferred from the soil to the atmosphere by conductive heat flow, and the amount of heat transferred to the surface by effluents from thermal phenomena (e.g., hot springs) over the same unit of time. The resulting sum is the "natural thermal power" (P) of an area. Thus $P = P_1 + P_2$, where P_1 represents the conductive heat flow, and P_2 represents the thermal energy contained in the fluid effluent. The total amount of energy stored underground (H) can be calculated by assuming that all thermal energy is dissipated to the surface, without resupply from subcrustal regions over a fixed period of geological time, (t). Given H from the equation $H = P \cdot t$, the recoverable fraction of H can be estimated using the concept of recoverability as discussed in the section on the volume method (Section 3.2.3). To avoid estimating the duration of natural hydrothermal discharge (t), an alternative method of analogy to other well-known areas is often used. This method is used most commonly in regions which have abundant thermal manifestations.

There are several flaws in the surface thermal flux method. First, the method is at best only semiquantitative. Even in areas of high natural fluid discharge where the method is most effective, either the duration of steady natural heat discharge must be guessed, or a subjective comparison must be

made with a developed area whose characteristics are assumed to be identical. In addition, areas of low natural discharge are likely to be grossly underestimated, while "blind" areas (e.g., Heber and East Mesa in the Imperial Valley in southern California) are commonly neglected. Particular problems derive from the measurement of conductive heat flow, and the measurement of the heat associated with thermal phenomena. Mass flow rates, which are essential for calculating the thermal energy contained in fluid effluent, have not been measured for most hot springs in the Northwest. Although flow rates are available for most springs, they are usually only "eyeball" estimates by geologists sampling the chemistry of the springs, and may contain large errors. Accurate assessment of conductive heat flow requires temperature gradient information, which can be obtained only from bore holes. Holes have not been drilled in the majority of geothermal sites in the study area, and where bore holes have been drilled, the data is proprietary. Thus the data required for accurate determination of natural thermal power are not available from most geothermal sites in the Pacific Northwest.

Finally, the thermal heat flux method gives only a minimum potential for a prospective geothermal site. A true potential commonly will be much higher. This is particularly true in areas of low or no natural fluid discharge. White (1965) states that "experience at some localities indicates that heat can be withdrawn at rates of 4 to more than 10 times the natural heat flow for at least 10 years without serious effect." Suyama et al. (1975) state that geothermal areas can be exploited at 10 to more than 100 times the natural heat output. Because the problems discussed above exist, the method of surface thermal flux has been rejected as a means of evaluating the geothermal resources of the Pacific Northwest region.

3.2.2 Planar Fracture Method

This method, developed primarily for use in the young flat-lying basalts of Iceland, was developed by Bodvarsson (1974). It is based upon a model consisting of a planar fracture in otherwise impermeable rock. Heat is transferred to a fracture by conduction and then along the fracture by flowing water. If the physical factors of initial rock temperature, recharge temperature, minimum outflow temperature, and production period are known, recoverable thermal energy can be calculated. This method can also

be extended to multiple fractures if the distance between the fractures is large enough to preclude thermal interference between them.

The main problem with the thermal fracture method is that it is designed for use in relatively flat-lying flood basalt terrains and therefore is not suited for a majority of geothermal areas which possess complex fracture geometries. In the Pacific Northwest, the method could be applied to the basalt terrains of the Columbia Plateau of Oregon and Washington, and the Snake River Plain of Idaho. Even here, however, the required physical parameters are usually not well enough known to achieve the desired degree of accuracy. In addition, use of this method would make comparisons with previous estimates (e.g., USGS Circular 892) very difficult.

3.2.3 Volume Method

The volume method is the most commonly used method of geothermal assessment, and is the one chosen for the evaluation of resources in the four-state study area. It is based on a calculation of the amount of heat energy, referenced to mean annual surface temperature, stored in a certain volume of rock. This calculation is accomplished by estimating a volume for the geothermal reservoir and then estimating the average temperature for the entire volume. Alternatively, a reservoir can be divided into a series of depth intervals corresponding to geohydrologic units, and a mean temperature estimated for each unit. Once the volume of the reservoir has been calculated, there are two slightly different methods to determine the amount of heat energy contained in the reservoir. One can either estimate a volumetric specific heat of the rock plus water in the reservoir, or one can estimate the porosity of the reservoir and calculate separately the heat contained in the solid phases and the pore fluids. The two methods of calculation should not differ by more than 5 percent if the total porosity is less than 20 percent and the pore fluid is liquid water. The second of these methods shows, however, that in nearly all geothermal reservoirs approximately 90 percent of the heat energy is stored in rock and only 10 percent of the energy is in water (Muffler and Cataldi, 1978).

The heat stored in a reservoir between its surface and a specific depth (dependent upon mean annual surface temperature) is termed the accessible resource base. Only a small portion of the accessible resource base can be

brought to the surface and used. This portion is called the geothermal resource. To evaluate the geothermal resource, the effective porosity of the reservoir must be known, and a model for the transport of fluid to the surface must be assumed. There are two principal types of models: (1) intergranular vaporization (boiling in place), and (2) intergranular flow of water (sweep process). These models are discussed in more detail in the following section. The amount of energy that can be extracted from a given volume of rock depends on many factors, including the amount of heat initially contained in the rock, porosity, initial temperature and pressure, wellhead temperature and pressure, and so on. Obviously, an accurate determination of a geothermal resource for a particular field requires abundant data obtained from production wells. These data are not available in areas where there are few or no drill holes. When data are not available, the concept of a "recovery factor" is commonly used. This permits the expression of recoverable geothermal energy as a percentage of thermal energy contained in a given subsurface volume. A recovery factor can range up to approximately 25 percent for hot-water systems (Muffler and Cataldi, 1978).

The popularity of the volume method to evaluate geothermal resources stems from two factors: (1) it is based on a series of geological and physical factors which can be determined theoretically for a specific area, and (2) it is similar to methods used in the evaluation of petroleum and mineral resources. Muffler and Cataldi (1978) feel that the volume method is the method best suited for the assessment of individual hydrothermal systems. A further advantage is that it permits direct comparison with results from previous regional assessments (i.e., USGS Circulars 726, 790, and 892) which use the same method.

There are two principal weaknesses associated with the volume method. The first concerns the estimation of the recovery factor. This value depends on an assumed fluid production model (i.e., either boiling in place or the sweep process), and on how the recovery factor for the particular model varies with temperature, effective porosity, and depth. For steam producing systems there are some data and theoretical work that allow evaluation of the recovery factor, but for hot water producing systems both the estimation of recovery factor and the manner in which it varies with

effective porosity are little more than educated guesses (Muffler and Cataldi, 1978).

A second weakness is that the method considers only the status quo underground and does not take into account the recharge of heat into the reservoir. Hydrothermal convection systems are dynamic, not static systems. This is particularly true for Basin and Range Province geothermal systems, where the concept of a geothermal reservoir is not strictly applicable. The use of the volume method does, however, result in a conservative calculation of the accessible resource base which is consistent with the philosophy of the assessment team. This is discussed more completely in the section on evaluation methodology. For the present, it is helpful to note that Muffler and Cataldi (1978)found that "resupply of heat during some tens of years of exploitation is unlikely to exceed 10-20 percent of the heat extracted from storage alone."

3.2.4 Methods of Magmatic Heat Budget

In volcanic areas, magma is intermittently supplied to the upper crust. Some magma is erupted at the surface as volcanic rocks, and some lodges in the crust as intrusions. These intrusions can either heat overlying hydrothermal systems or they can be themselves targets of exploration. Estimates of the size, position, and age of an intrusion, combined with an analysis of the cooling history, is used to estimate the accessible resource base associated with an intrusion.

Unfortunately, this method gives little insight into the fraction of the accessible resource base that might be recoverable (i.e., the actual geothermal resource). Because of this limitation, the magmatic heat budget method is not considered an acceptable method for evaluating resources associated with hydrothermal convection systems. For those sites in the study area with no associated surface thermal phenomena, however, it is necessary to use a variation of this method to derive some sort of estimate of the geothermal potential of the site. In these cases, the method developed by Smith and Shaw (1975) is used. Smith and Shaw hypothesize that upper crustal magma chambers are formed by more silicic (silica rich) magmas, while mafic (silica poor) magmas rise directly to the surface without forming magma chambers. This approach estimates volumes of

magma chambers (primarily by inference from the associated volume of volcanic rocks and geophysical data) and infers the age of emplacement (approximated by the age of the youngest silicic volcanic rock) of the intrusion. The amount of geothermal energy left in the intrusion and adjacent country rock is estimated using conventional calculations of conductive heat loss. Convective cooling is assumed to be offset by the effects of magmatic pre-heating and additions of magma after emplacement.

As stated above, the main problem with the magmatic heat budget method is that it can give only a broad indication of the accessible resource base, and then only in geologically young volcanic regions. The method involves several assumptions, including: (1) the age of the intrusion, (2) the size of the intrusion, and (3) that the cooling effects of hydrothermal convection are offset by magmatic pre-heating and additions of magma after the time of emplacement. The last assumption is particularly questionable.

In spite of these objections, it has been considered necessary to use the method of magmatic heat budget as developed by Smith and Shaw (1975) to arrive at an estimate of geothermal potential for those sites in the study area that do not possess associated surface thermal phenomena (i.e., "blind" geothermal resource sites).

3.3 Detailed Resource Evaluation Methodology

3.3.1 Introduction

In the following sections the detailed resource evaluation methodology for each of the following temperature ranges is described:

(1) High temperature hydrothermal convection systems (greater than 90°C).

(2) Blind geothermal systems.

(3) Low temperature systems (less than 90°C).

The section on high temperature systems includes a brief discussion of methods used to evaluate the statistical certainty of these estimates, and

the methods used to evaluate reservoir volumes and temperatures. Discussions of particular problems associated with Basin and Range and Cascade Range systems are reserved for a later section.

3.3.2 High Temperature Hydrothermal Convection Systems

High temperature geothermal systems are defined as those systems with estimated reservoir temperatures greater than 90°C. The 90°C division was chosen to simplify comparisons between this report and USGS Circulars 726 and 790. Circular 726 originally divided hydrothermal convection systems into three temperature ranges: (1) above 150°C; those suitable for the generation of electricity; (2) 90°C to 150°C; those systems attractive for space and process heating; and (3) less than 90°C; those systems likely to be used only in locally favorable circumstances. This report maintains these temperature divisions with slightly different emphasis. Due to recent advances in wellhead binary generator technology, we consider that hydrothermal systems with temperatures in the 90° - 150°C range are capable of generating electricity. We consider them to be high temperature systems and attempt to estimate their electrical generation potential as well as their direct use potential.

Before proceeding with a detailed description of the evaluation methodology, it is necessary to define two terms. The **accessible resource base** is defined as all geothermal energy within a specified volume of rock and at a specified temperature referenced to mean surface temperature (Brook et al., 1979). The **resource** is that fraction of the accessible resource base that can be produced at the wellhead under reasonable economic and technological assumptions (Brook et al., 1979). The purpose of

the evaluation methodology is to estimate the magnitude of the accessible resource base, the resource, and electricity that might be produced from each high temperature geothermal system in the four-state area.

High temperature hydrothermal systems can be classified into vapor-dominated or hot-water-dominated systems, depending upon whether steam or liquid water is the continuous pressure controlling phase in the reservoir. Vapor-dominated systems are rare. The Geysers in northern California is the most notable example in the United States. With the possible exceptions of Newberry Volcano and some of the High Cascade composite volcanos of Washington and Oregon, vapor-dominated systems are not expected to be found in the study area. Therefore, in the sections which follow, vapor-dominated systems are not considered. The reader is referred to the work of Brook et al. (1979) in USGS Circular 790 for information concerning the evaluation of vapor-dominated systems. The following description of the resource evaluation methodology is taken from Brook et al. (1979).

3.3.2.1 Determination of Accessible Resource Base

The calculation of the accessible resource base is a relatively straightforward process. Reservoir temperature, subsurface area, and thickness are estimated for each hydrothermal system. The accessible resource base is then calculated from the equation:

$$q_R = pc * a * d * (t - t_{ref})$$

where:

q_R	=	reservoir thermal energy in joules (J)
pc	=	volumetric specific heat of rock plus water (2.7 $J/cm^3/^oC$)
a	=	reservoir area
d	=	reservoir thickness
t	=	reservoir temperature
t_{ref}	=	mean annual surface temperature

The volumetric specific heat (pc) is calculated assuming the rock volumetric specific heat to be 2.5 $J/cm^3/^oC$ and the reservoir porosity to be 15 percent.

3.3.2.2 Statistical Methods

BPA has requested an assessment of the relative certainty of resource estimates in this report. These estimates consist of a mean and standard deviation for estimates of reservoir temperature, area, thickness, and volume, and a standard deviation for the estimate of accessible resource base (Reservoir thermal energy column in Appendix 1). Triangular probability densities are used to derive these certainty estimates.

As an example of difficulties which can occur when evaluating geothermal resources by the volume method, consider an estimate of reservoir thickness. In a reservoir that lacks drillhole data, both the thickness of the reservoir and the possible ranges of thickness are unknown. Even when some data from a limited number of holes exist, it is impossible to know what percentage of the reservoir possesses thicknesses similar to those which have been encountered. The concept of subjective probability is used in these circumstances when all possible outcomes are not known, and the frequency of occurrence of a known outcome cannot be predicted. Triangular probability densities are an example of subjective probability.

Three values are required for triangular probability densities. The **minimum** is the absolute value below which no value can exist. The probability is zero that a value less than the minimum exists in the reservoir. The **most likely** is the value which should occur most frequently (i.e., the value that has the greatest likelihood of occurring). It is the mode of the distribution, not the mean. The **maximum** is the absolute ceiling of the distribution. The probability is zero that a value greater than the maximum exists in the reservoir. Human judgment based on geology, geophysics, and geothermometry is used to select the minimum, most likely, and maximum values for reservoir area, thickness, and temperature. Triangular probability densities are used because they are the only way to approximate a distribution from only

three points. The three values (the minimum, most likely, and maximum) can also be used as input into a Monte Carlo simulation program. The program converts the three values into a cumulative frequency curve which expresses probabilities of occurrence. Monte Carlo simulations were not used for this project, however. Instead, statistical means and standard deviations were calculated using the following formulas from Nathenson (1978):

where

t_1, A_1, Th_1 = minimum temperature, area, and thickness

t_2, A_2, Th_2 = most likely temperature, area, and thickness

t_3, A_3, Th_3 = maximum temperature, area, and thickness

t_o = mean annual surface temperature

t_{avr} = mean temperature

V = volume

Q = reservoir thermal energy (i.e., accessible resource base)

Var( ) = variance of a particular parameter (e.g., Var (t) is the variance of temperature)

$$t_{avr} = (t_1 + t_2 + t_3)/3$$

$$Var\ (t) = ((t_2 - t_1)^2 + (t_3 - t_2)^2 + (t_2 - t_1)(t_3 - t_2))/18$$

Substitution of A and Th for t in the above equations results in the means and standard deviations for reservoir area and thickness, respectively.

$$V_{avr} = A_{avr} * Th_{avr}$$

$$Var\ (V) = (Var\ (A) + A_{avr}^2)(Var\ (Th) + Th_{avr}^2) - A_{avr}^2 * Th_{avr}^2$$

$$Q_{avr} = pc * (t_{avr} - t_o) * A_{avr} * Th_{avr}$$

$$Var\ (Q) = (pc)^2 * (Var\ (t) + (t_{avr} - t_o)^2) * (Var\ (A) + A_{avr}2) * (Var\ (th) + Th_{avr}^2) - (pc)^2 * (t_{avr} - to)^2 * A_{avr}^2 * Th_{avr}^2$$

For all of the above variables, the standard deviation is simply the square root of the variance.

Triangular probability densities do not represent the real world because they do not give precise representations of either normal or lognormal distributions. Because parameters used to evaluate geothermal reservoirs (reservoir temperature, area, and thickness) tend to have lognormal distributions, there is a pronounced tendency for triangular probability distributions representing these parameters to be sharply skewed to the right. Thus the triangular distributions tend to **overestimate** mean values compared to real world lognormal distributions. For example, the average temperature of a reservoir as calculated from the above equations may be significantly higher than what a geologist feels is the most likely or best temperature for the reservoir. To combat this problem, Appendix 2 contains two estimates of both reservoir thermal energy (i.e., accessible resource base) and electrical energy. One is based upon mean reservoir parameters and the other is based upon most likely reservoir parameters.

3.3.2.3 Temperature Estimates

The chemical and isotopic composition of hot springs can be used to estimate subsurface temperatures. The accuracy of the estimates depends upon the degree to which the following assumptions are fulfilled (Fournier et al., 1974):

1. Temperature-dependent reactions at depth control the concentration of the constituents used in the geothermometer.

2. All constituents in a temperature-dependent reaction are sufficiently abundant (i.e., supply is not a limiting factor).

3. Water-rock equilibrium occurs in the reservoir at the reservoir temperature.

4. Little reequilibration or change in composition occurs at lower temperatures as the water flows from the reservoir to the surface.

5. The hot water coming from deep in the system does not mix with colder shallow groundwater.

Although these assumptions may be fulfilled at some locations, they are not usually fulfilled everywhere. In particular, numbers 4 and 5 commonly may be invalid. Three geothermometers, the silica, Na-K-Ca, and the sulfate-isotope, are used to estimate most reservoir temperatures in this report. A brief discussion of each geothermometer follows.

3.3.2.3.1 Silica Geothermometer

Concentrations of silica in a thermal water depend principally on the temperature-dependent solubility of quartz, chalcedony, alpha cristobalite, or amorphous silica (Fournier,1973; Fournier and Rowe, 1966). Several factors must be considered when applying the silica geothermometer (Fournier, 1980): (1) the temperature range over which the equations are valid, (2) effects of steam separation, (3) control of aqueous silica by solids other than quartz, (4) possible polymerization and/or precipitation of silica before sample collection, (5) possible polymerization of silica after sample collection, (6) the effect of pH upon quartz solubility, and (7) possible dilution of hot water with cold water before the thermal water reaches the surface. Consideration of number 4 above is easily solved through the use of proper sampling procedures. The remaining factors are discussed briefly in more detail below. Except where noted, the following discussion is taken from Fournier (1980).

The equations used to describe the solubility of quartz are relatively accurate ($\pm$ 2°C) over the temperature range 0°-250°C. Above 250°C they should not be used.

Because silica concentration in a residual liquid increases in proportion to the amount of boiling that has occurred, it is necessary, when using the silica geothermometer, to correct for the amount of steam that has formed. Fournier (1980) gives two equations that can be used to calculate subsurface temperatures when equilibrium with quartz is assumed. The first assumes adiabatic (no net heat input or output) cooling and is used for vigorously boiling springs with large mass flow rates. The second, which is used for lower flow rate non-boiling springs, assumes conductive cooling. If cooling of the fluid during ascent was partly adiabatic and partly conductive, the true reservoir temperature should lie between the values given by the adiabatic and conductive equations.

Nearly all geothermal reservoirs contain quartz, which is the most stable and least soluble polymorphic form of silica within the temperature and pressure range found in geothermal systems. In the temperature range 200°-250°C, water reaches equilibrium with respect to quartz solubility in a few hours or a few days, and in most natural waters above 150°C (and in some waters below that temperature) quartz appears to control the dissolved silica concentration. Other silica phases may also persist metastably within the stability field of quartz, and under special conditions may control dissolved silica concentrations. These other forms of silica are more soluble than quartz, and reservoir temperatures calculated assuming equilibrium with quartz may be too high. Because most groundwaters which have not attained temperatures greater than 80-90°C have silica concentrations greater than those predicted by the solubility of quartz, care must be taken in interpreting the silica geothermometers of low temperature

springs and wells. In these cases a more reasonable estimate of reservoir temperature may be obtained if equilibrium with amorphous silica or chalcedony is assumed.

Although at high temperatures equilibrium with quartz is reached very rapidly, the rate of quartz precipitation actually decreases as temperature decreases. Below 100°C solutions may remain supersaturated with quartz for years. For reservoirs with temperatures in the range 225°-250°C, little quartz precipitation will occur if upflow is rapid (i.e., less that a few hours). However, for those reservoirs with temperatures greater that 250°C, some quartz will probably precipitate in the deep, hot part of the system as cooling occurs. Additionally, if adiabatic cooling occurs, fluids starting at temperatures greater than 225°C become saturated with respect to amorphous silica before reaching the surface. Because amorphous silica precipitates more rapidly than quartz at comparable temperatures, considerable silica may be lost from the system. Due to combinations of the above effects, the quartz geothermometer rarely indicates reservoir temperatures greater than 225°-250°C, even where higher reservoir temperatures are known to exist.

Alkaline (high pH) solutions cause an increase in quartz solubility. The effect is most pronounced at about 175°C, where a pH of 7.6 will cause an increase in quartz solubility of 10 percent. However, the pH of most high-temperature systems is below 7.5 due to buffering reactions in the reservoir, and pH values higher than 7.5 are most often due to the loss of carbon dioxide after the water leaves the high temperature environment. In general, a pH correction should not be applied to alkaline waters unless it can be determined that the waters became alkaline and then dissolved additional silica in response to the rise in pH. Since it is very difficult to show that silica was dissolved after a rise in pH, a pH correction is not normally applied, particularly if there is other supporting evidence that the water came from a higher-temperature environment at depth. In this report pH corrections are not made unless the correction is at least 10°C. If a pH

correction is applied, the assumption is made that the pH in the spring is the same as in the associated thermal reservoir.

The dilution of thermal water by cooler water is a frequent occurrence. If water-rock equilibrium is attained after mixing, application of the silica geothermometer will give the temperature of the last equilibration. If equilibrium has not been attained after mixing, direct application of the silica geothermometer will result in a reservoir temperature that is too low. The problem is deciding whether mixing has occurred. The simplest evidence is a linear trend between measured spring orifice temperatures and chloride concentrations. If mixing has occurred, it is possible to calculate the temperature of the thermal component if sufficient chemical and isotopic data are available for both the thermal and the cold waters. These calculations assume that chemical equilibrium has not occurred at or below the mixing temperature and that there has been negligible conductive heat loss.

Many of the springs from Washington's initial list of potential high-temperature sites have cold CO_2-charged waters. Waters of this type present a special problem because they have silica concentrations that approach saturation with respect to amorphous silica. Apparently, the rate at which silicates dissolve is controlled, in part, by the concentration of dissolved CO_2. At higher concentrations, the silicates dissolve faster (Wildman et al., 1968). These waters were not included in the final high temperature site list because the silica concentrations are a function of the high CO_2 concentrations, and not high subsurface temperatures.

Due primarily to the effects of silica precipitation and mixing, reservoir temperatures estimated from the silica geothermometer

tend to be minimums. McNitt (1976), in an examination of 30 areas for which there existed both surface chemical and subsurface temperature data, found that:

1. For 6 reservoirs with temperatures in the range 106°-160°C, the silica geothermometer overestimated the reservoir temperature by an average of 18°C, with a range of +5° to +36°C.

2. For 22 reservoirs with temperatures in the range 160°-300°C, the silica geothermometer underestimated the reservoir temperature by an average of 60°C, with a range of -8° to -122°C.

3. For 2 reservoirs with temperatures greater than 300°C (Salton Sea and Cierro Prieto), the silica geothermometer estimated temperatures of 252°C and 273°C, respectively.

3.3.2.3.2 Na-K-Ca Geothermometer

The Na-K-Ca geothermometer (Fournier and Truesdell, 1973) was developed specifically to deal with calcium-rich waters that give anomalously high calculated temperatures with the Na/K method (Fournier, 1980). As is the case with most geothermometers, the effects of mixing with cold, dilute waters and boiling must be considered when applying the Na-K-Ca geothermometer. Boiling tends to cause the loss of CO_2 from the system, which can cause the precipitation of calcium carbonate ($CaCO_3$). The loss of Ca^{++} ions from solution generally results in Na-K-Ca calculated temperatures that are too high (Fournier, 1980), a fact that must be taken into account for any spring which is depositing calcite.

The effects of dilution on the Na-K-Ca geothermometer are negligible if the hot water is much more saline than the cold, and the mixture contains a hot water fraction of at least 20-30 percent. With a hot water fraction of less than 20-30 percent, the effects of mixing should be considered, as the calculated temperature is likely to be significantly low (Fournier, 1980). The

hot water fraction can be estimated using the silica mixing model of Fournier and Truesdell (1974).

Fournier and Potter (1979) demonstrated that the Na-K-Ca geothermometer gives anomalously high results when applied to magnesium rich waters. They published corrections to the geothermometer for such waters which produce better agreement between the silica and cation geothermometers, particularly in the range 90°-150°C. It must, however, be borne in mind that high magnesium concentrations in thermal waters (normal concentrations in high temperature waters range from 0.001 - 0.1 ppm, Ellis and Mahon, 1977) tend to indicate that water-rock reactions have occurred at relatively low temperatures during fluid ascent, and that the application of the magnesium correction to waters which have increased magnesium concentrations in this manner will result in anomalously low estimates of reservoir temperature. There is no good rule of thumb to indicate where and when not to apply the magnesium correction to the Na-K-Ca geothermometer. In general, it is best to remember that high magnesium concentrations indicate that some reequilibration has probably occurred during ascent, and that all chemical geothermometers must be applied with caution (Fournier, 1980).

Both the Na-K-Ca geothermometer and the Na/K geothermometer (not discussed in this report) are based upon chemical equilibria between thermal waters and alkali feldspars. In acid waters, equilibrium would not be established with feldspars, and these geothermometers do not apply. They also do not apply to situations where the reservoir rocks contain unusually high or low concentrations of a particular alkali unless there are direct correlations between measured temperatures and alkali concentrations (Ellis and Mahon, 1977).

3.3.2.3.3 Sulfate-Water Isotope Geothermometer

There are many natural processes that cause variations in the isotopic compositions of natural waters, the classic example being the evaporation and condensation of water. During evaporation,

light molecules of water ($H_2{}^{16}O$) are more volatile than molecules containing a heavy isotope ($HD^{16}O$ or $H_2{}^{18}O$, D is deuterium), so that water which evaporates from the ocean is depleted by about 12-15 $^o/oo$ in ^{18}O and 80-120 $^o/oo$ in deuterium with respect to ocean water (Panichi and Gonfiantini, 1978). Similarly, during condensation, the less volatile heavy isotopes condense preferentially, leaving a residual vapor even more depleted in D and ^{18}O. In the above discussion, the per mil (parts per thousand, $^o/oo$) notation is used. Differences from isotopic standards are expressed as:

$$d\ (^o/oo) = ((R_x/R_s) - 1) * 1000$$

where R_x is the isotopic ratio in the unknown (e.g., $^{18}O/^{16}O$, D/H, etc.) and R_s is the same ratio in the standard. The standard for water is standard mean ocean water (SMOW) (Craig, 1961).

The fractionation of stable isotopes is often dependent upon temperature, and several elements have been used as isotopic geothermometers (e.g., ^{13}C in the carbon dioxide-methane system, hydrogen in methane-hydrogen and water-hydrogen systems, and oxygen in the carbon dioxide-water vapor system). The most useful isotopic geothermometer for liquid-dominated geothermal fields is based on the fractionation of oxygen between sulfate (and bisulfate) ions and water (Panichi and Gonfiantini, 1978). The isotopic exchange rate between sulfate and water is slow in alkaline to neutral solutions and increases as pH increases (Lloyd, 1968). Assuming a pH of 7, which is close to the actual pH of most deep geothermal systems, the time to reach 99.9 percent equilibrium is 2 years at 300°C, 18 years at 200°C, and as much as 500 years at 100°C (Panichi and Gonfiantini, 1978). Although these are long periods of time, the residence times of waters in most geothermal reservoirs appear to be sufficient to ensure isotopic equilibrium. The water and/or steam from geothermal fields is generally tritium free, indicating ages of 25 years or more (Panichi and Gonfiantini, 1978). These relatively slow isotopic exchange rates are advantageous because once isotopic equilibrium is

achieved in the reservoir, little or no reequilibration occurs as the fluid cools during movement toward the surface.

The sulfate-water geothermometer is adversely affected by steam separation during cooling, mixing with cold waters, and the oxidation of hydrogen sulfide (H_2S) at low temperatures.

If steam separation occurs during cooling, the isotopic composition of water changes. The fractionation of ^{16}O and ^{18}O between water and steam is temperature dependent, and equilibrium occurs very rapidly (essentially instantaneously) at temperatures as low as 100°C (Fournier, 1980). Therefore, if water has cooled adiabatically (i.e., by boiling) to a temperature of approximately 100°C during its rise to the surface, the isotopic composition of the liquid water remaining at the cessation of boiling will depend on whether steam has escaped continuously over a range of temperatures or whether all the steam remained in contact with the liquid and separated at the surface at the final temperature of 100°C (Truesdell et al., 1977).

Boiling, however, does not preclude the use of the sulfate-water geothermometer. McKenzie and Truesdell (1977) demonstrated that temperature estimates could be generated for three end-member models: (1) conductive cooling, (2) one step steam loss at any specified temperature, and (3) continuous steam loss (Fournier, 1980). For example, conductive cooling is assumed for springs which emerge well below boiling, and the one step steam loss model is used when water is produced from a well and steam is separated at a known temperature (Fournier, 1980).

Mixing of thermal water with cooler water can adversely affect the validity of the sulfate-water geothermometer, even if the cold component contains no sulfate. To correct the estimated reservoir temperature the isotopic composition of the water must be corrected back to the isotopic composition of the hot water fraction prior to mixing (Fournier, 1980).

Contamination by a small amount of sulfate produced at low temperatures by the oxidation of hydrogen sulfide can cause large errors in the estimates produced by the sulfate-water geothermometer (Fournier, 1980). The oxidation of H_2S often reduces the pH of affected springs to abnormally low values, but if pH's are relatively neutral, and analytical data are available for only one or two springs, the addition of small amounts of sulfate may be very difficult to detect. In general, if analytical data are available for several springs, and they all have the same chloride to sulfate ratio, then the oxidation of H_2S is probably unimportant (Fournier, 1980). If the chloride to sulfate ratios do vary, the water with the highest chloride to sulfate ratio has the best chance of being unaffected by H_2S oxidation (Fournier, 1980).

The main advantage of the sulfate-water geothermometer is that isotopic reequilibration does not occur as the fluid cools, so that a temperature indicated by the geothermometer tends to represent an actual reservoir maximum temperature. The disadvantage is that the maximum temperature indicated may be from a deep, particularly hot portion of the reservoir that is not reachable by current drilling technology. If the sulfate-water isotope geothermometer is selected as the maximum reservoir temperature, the resulting mean reservoir temperature will be too high. Consequently, the sulfate-water geothermometer must be selected as a maximum reservoir temperature with care, particularly when the quartz and Na-K-Ca geothermometers show close agreement at a significantly lower temperature.

The particular geothermometers selected for use at any one site vary depending on fluid chemistry. In general, however, maximum reservoir temperatures are based on either the quartz or the Na-K-Ca geothermometers. Occasionally the sulfate-water isotope geothermometer is used as a maximum, but only when there is reason to think that it represents a reasonable maximum for the system under investigation. The most likely reservoir temperature for high temperature systems is usually based on either the quartz geothermometer or the Na-K-Ca geothermometer. The minimum

reservoir temperature is nearly always based on the silica geothermometer assuming equilibrium with a form of silica other than quartz (usually chalcedony).

3.3.2.4 Volume Estimates

3.3.2.4.1 Subsurface Area

The estimation of subsurface area represents the largest uncertainty in evaluating the magnitude of the accessible resource base. Only one system in the study area (Raft River, Idaho) has been drilled to the extent necessary to adequately determine reservoir area. For the remaining systems, indirect evidence must be used in estimating areas. All available evidence (geologic, geophysical, and geochemical) is used in making these estimates. For systems where the only surface manifestation is a single spring or well or a group of springs or wells in a small area, USGS Circular 790 assumes default values for minimum, most likely, and maximum reservoir areas of 1, 2, and 3 km^2, respectively. These values are believed by Brook et al., (1979) to be representative of smaller hydrothermal systems, and are comparable to areas determined for many smaller systems where geophysical or geologic evidence forms a more solid basis for the estimates. Other methods used by Circular 790 to estimate reservoir area include similar water chemistry combined with similar surface geology for more widely spaced springs and wells, the extent of surface alteration, surface heat flow anomalies, and resistivity anomalies. This report utilizes the reservoir areas of Circular 790 unless more recent data is available.

3.3.2.4.2 Thickness

Estimates of reservoir thickness assume that a reservoir is uniformly thick over the entire area of the reservoir. This assumption is rarely valid, but reservoirs are so complex and the level of knowledge so limited that a more refined model is not justified. USGS Circulars 726 and 790 assume that the bottom of any given geothermal reservoir lies at 3 km, which is the approximate maximum depth of geothermal drilling. The Technical

Review Committee of this study has determined that 3 km remains the maximum practical depth for drilling in high temperature geothermal areas. Default values for minimum, most likely, and maximum depth the top of the reservoir are 0.5, 1.5, and 2.0 km, respectively. The resulting minimum, most likely, and maximum reservoir thicknesses are 1.0, 1.5, and 2.5 km, respectively. This report uses these same default values for systems outside the Basin and Range Province; but uses slightly different default values for sites within the Basin and Range Province. Benoit and Butler (1983) present drilling data from 11 Basin and Range geothermal systems. An analysis of only the producing wells in these 11 systems results in a minimum, most likely, and maximum depth to the top of the reservoir of 0.5, 1.3, and 2.5 km, respectively; and a minimum, most likely, and maximum reservoir thickness of 0.5, 1.7, and 2.5 km, respectively (assuming the bottom of the reservoir is at 3 km). Whatever the value chosen for reservoir thickness, the fact remains that for most reservoirs the uncertainties involved in estimating thickness are small compared to those involved in estimating area.

3.3.2.5 Determination of Resource and Electrical Energy

Two major steps are necessary to determine the amount of thermal energy obtainable from a hydrothermal convection system. The first is to estimate the fraction of accessible resource base that is recoverable at the surface under reasonable assumptions of future technology and economics (i.e., the resource). The second is to estimate the efficiency with which the resource can be converted into electrical energy.

As a first step, it is necessary to calculate the geothermal recovery factor (Rg), which is the ratio of geothermal energy recovered at the wellhead (q_{wh}, the wellhead thermal energy of Appendix 1) to the geothermal energy originally in the reservoir (q_R, the reservoir thermal energy of Appendix 1):

$$Rg = q_{wh}/q_R$$

For liquid dominated systems the derivation of Rg is based on the sweep process of heat extraction (Bodvarsson, 1974; Nathenson, 1975). Water stored in the reservoir is heated by conduction from the reservoir rocks. The hot water with lower density rises and is discharged from the system (either via natural discharge or production wells) and colder, more dense water sweeps into the reservoir (either via natural recharge or injection), and is in turn heated by conduction from the reservoir rock. Recharge balances discharge, so boiling in the reservoir does not occur. Nathenson (1975) estimates that 50 percent of the thermal energy in an ideal reservoir may be recovered in a sweep process, assuming that total porosity = effective porosity = 20 percent. Nonideal reservoir behavior, due to the fact that much of the reservoir volume may not be porous and permeable, is assumed to reduce the geothermal recovery factor by one-half (Nathenson and Muffler, 1975). Therefore, for liquid-dominated systems, Brook et al., (1979) assume a geothermal recovery factor of 25 percent (i.e., $q_{wh} = .25 * q_R$).

To convert thermal energy to electricity, the heat in the reservoir must first be converted to mechanical energy. Available work (WA) is the maximum amount of work that can be obtained from a given amount of thermal energy. Brook et al., (1979) give the following relationship to calculate available work, assuming that the initial wellhead condition and final state are saturated liquids and that the reference temperature is 15°C (288°K).

$$WA = \Delta H - T\,\Delta S = M_{WH}\,(h_{WH} - h_o - T_o(S_{WH} - S_o))$$

where:

ΔH	=	enthalpy
ΔS	=	entropy
T	=	temperature (°K) of the surrounding to which the heat is rejected
M_{WH}	=	mass of fluid produced at the wellhead
h_{WH}	=	enthalpy per unit mass of fluid at the wellhead
h_o	=	enthalpy per unit mass of fluid at the final state
T_o	=	rejection temperature (°K)

S_{WH} = entropy per unit mass of fluid at the wellhead

S_o = entropy per unit mass of fluid at the final state

In the above equation $M_{WH} = q_{WH}/(h_{WH} - h_o)$, where h_o is the enthalpy per unit mass of water at 15°C.

If production well data are available, the temperature and mass of fluid produced at the wellhead are known, and h_{WH} can be determined from steam tables. If production well data are not available, which is the case for nearly all sites in the four-state area, the enthalpy of liquid water at the wellhead (h_{WH}) can be estimated by subtracting the energy loss due to raising the water against gravity from the enthalpy of the water in the reservoir, h_R:

$$h_{WH} = h_R - (Z_R * g)$$

where:

h_R = enthalpy per unit mass of water in the reservoir (determined from steam tables)

Z_R = depth to middle of reservoir in meters

g = acceleration of gravity = 0.098 m/s^2

The entropy of water at the wellhead (s_{WH}) is obtained from steam tables by using the corresponding value for h_{WH} calculated above. Wellhead temperature is not needed to determine either h_{WH} or s_{WH}. The mass of water produced at the wellhead is given by:

$$m_{WH} = q_{WH}/(h_{WH} - h_o)$$

where h_o is the enthalpy per unit mass of water at 15°C.

Brook et al., (1979) summarize the calculation of wellhead thermal energy and available work in graphical form, reproduced here as Figure 3.1. In Figure 3.1 (taken from Brook et al., 1979) the ratio of available work to reservoir thermal energy (W_A/q_R) is plotted on the ordinate and reservoir temperature (T_R) is plotted on the abscissa.

The columns labeled "W_A/q_R" and "Best W_A/q_R" in Appendix 1 are both derived from this figure. The first utilizes mean reservoir temperature for the derivation, and the second utilizes most likely reservoir temperature. The column labeled "Wellhead Available Work" is the product of "W_A/q_R" and "Reservoir Thermal Energy" (i.e., $W_A = (W_A/q_R) * q_R$).

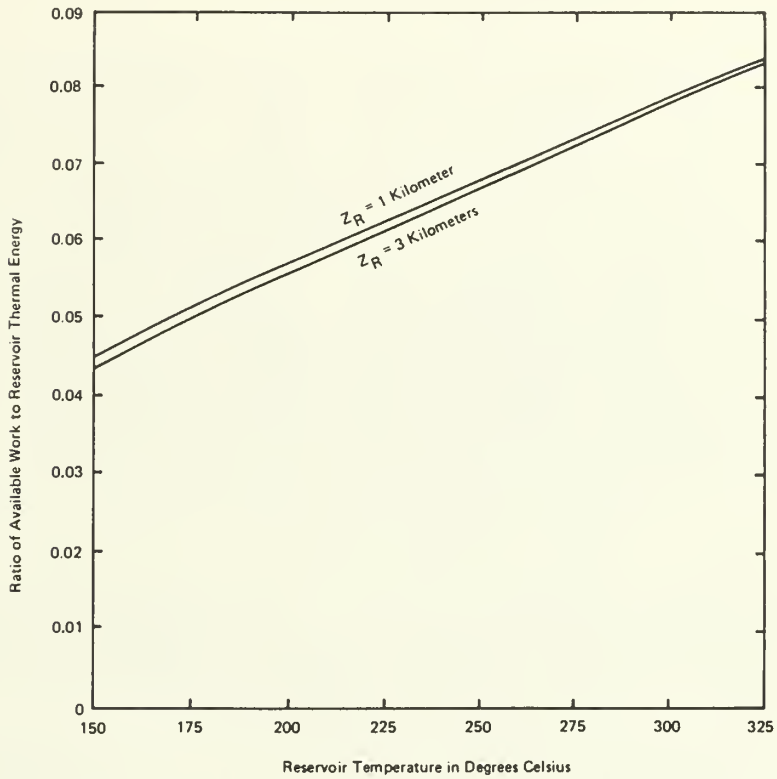

Figure 3.1 — Ratio of available work to reservoir thermal energy for hot water systems plotted against reservoir temperature for two values of depth to the middle of reservoir.

The electrical energy that can be obtained from a geothermal reservoir is calculated from the formula:

$$E = W_A * N_u$$

where:

N_u = thermal utilization factor.

The thermal utilization factor takes into account mechanical and other losses which occur in the conversion of mechanical to electrical energy

in a real power cycle. Figure 3.2, taken from Brook et al., (1979), plots utilization factor versus wellhead temperature for several conversion technologies. The construction of Figure 3.2 assumes a condensing temperature of 40°C. Once electrical energy has been determined, electrical power (MWe) is determined by dividing electrical energy (E) by the expected lifetime of the field (30 years). The thermal utilization factors and electrical energy estimates of Appendix 1 were determined in the above manner.

The thermal utilization factors of Figure 3.2 have only been tabulated for temperatures above 150°C. Thermal utilization factors for intermediate temperature (90°-150°C) systems (see Figure 3.3) were derived from Figure 1 of a paper entitled "Engineering Analysis of Organic Rankine Cycle." This paper is actually a computer program developed for the Oregon Department of Energy by Gene Ryan of the Oregon Institute of Technology. The program has been used in this study to aid in evaluating potential wellhead generation sites, and is

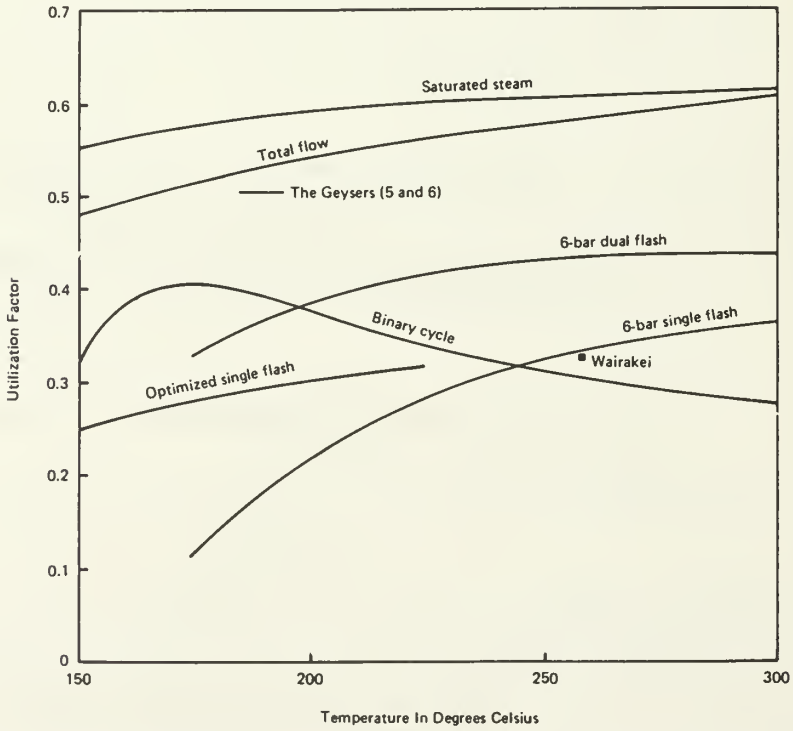

Figure 3.2 – Utilization factors for electric power generation calculated for several conversion technologies as a function of temperature.

discussed in more detail in another section of this report. Figure 3.3 assumes binary wellhead technology, and does not take into account parasitic losses.

3.3.3 "Blind" High Temperature Systems

"Blind" high temperature geothermal sites are those that do not possess surface thermal manifestations (e.g., hot springs, geysers, fumaroles, etc.). There are several sites in the study that fall into this category, most of which are located in Oregon. These sites can be recognized in the tables of Appendix 1 in several ways: (1) only a most likely reservoir area is listed, there are no values for minimum and maximum areas, (2) no values for reservoir thicknesses are listed, (3) variances and standard deviations for reservoir thermal energy are not listed, and (4) there is usually a note in the remarks section to the effect that the site represents a "blind resource" or that it is an "intrusive cooled to ambient (?)." Because most of the "blind" sites in the study area are related to young volcanism of one type or another, they are also listed in the tables of Igneous-Related Systems of Smith et al. (1978) and Smith and Shaw (1975, 1979).

The quantitative estimation of the geothermal potential of "blind" resources is even more difficult than the evaluation of hydrothermal systems. The lack of surface thermal phenomena makes the quantitative estimation of reservoir temperature on a site specific basis impossible (assuming that bore hole data do not exist). Because they lack surface thermal phenomena, these sites have, in most cases, been ignored as potential geothermal resources. The result is that relatively detailed geologic mapping and geophysical studies are often lack making the resource estimates of Appendix 1 tenuous. The estimates of electrical generation potential are particularly suspect. The main problem is that, although heat conduction theory allows the formulation of a reasonable cooling model and hence a reasonable estimate of accessible resource base, no system of this type has yet been exploited for geothermal energy. As a result, there is no good idea of what the appropriate geothermal recovery factor should be. The factor used in the calculations of Appendix 1 (25 percent) is almost certainly too

Smith et al., (1978) present the following data in their tables of the magnitude and heat content of identified volcanic systems: (1) Magma chamber area, usually determined from either the distribution of volcanic vents or the area of the caldera. This value is listed in Appendix 1 as the most likely reservoir area. (2) Volume of the magma chamber. Volumes are estimated from the distribution of vents, caldera size, or from extrapolation of silicic ejecta volume. The calculations of magma chamber volume in Smith et al., (1978) assume that the magma chamber extends from 2.5 to 10 km. The tables give a range of values for volume and a best estimate. These values are reflected in the mean and standard deviation for reservoir volume listed in Appendix 1. Smith and Shaw (1975) note that magma chamber volumes can be approximated within an order of magnitude using the above methods. (3) Total heat (Q_t), or the thermal energy liberated if the entire magma chamber cools from an initial temperature of 850°C to a final temperature of 300°C. This calculation assumes that the magma is emplaced at a temperature of 850°C and is completely solid at a temperature of 650°C. It also assumes that the latent heat of crystallization of the magma is 272 J/g, the heat capacity is 1.3 J/g/°C, and the mean density of the magma is 2.5 g/cm^3. (4) The thermal energy that remains in the system at the present time (Q_n). This is the accessible resource base for igneous-related systems (Smith et al., 1978). However, because much of the heat energy lies at depths greater than 3 km, it is not the number listed as reservoir thermal energy in Appendix 1 . Smith and Shaw's (1975) estimate is based on the calculation of the time required for the temperature gradient at the surface to be significantly increased over its original value by conductive heat transfer in dry rocks if a magma chamber is suddenly emplaced with its top at a depth of 4 km. If the intrusive was emplaced less than 300,000 years before present (y.b.p.), little heat has been lost from the system unless there has been significant convection in the roof rocks for much of that time. (5) The thermal energy transferred to the roof rocks between the assumed time of emplacement of the intrusive body and the present (Q_r).

As stated above, the reservoir thermal energy of Appendix 1 is not taken to be Q_n because much of the energy associated with the intrusive lies at depths greater than 3 km. A more reasonable estimate of accessible resource base would be obtained if only that energy still residing in the roof

rocks above the pluton is considered. This number can be obtained from the data of Smith et al., (1978) by the relationship:

$$Q = Q_n - (Q_t - Q_r)$$

where:

Q	=	thermal energy remaining in the roof rocks at the present time
Q_n	=	thermal energy remaining in the system
$(Q_t - Q_r)$	=	thermal energy remaining in the intrusive

It is Q that is listed in Appendix 1 as the reservoir thermal energy.

Once a value for reservoir thermal energy has been determined, the calculation of electrical energy proceeds exactly as described for high temperature hydrothermal convection systems. The wellhead thermal energy is determined from Figure 3.1, a thermal utilization factor is taken from Figure 3.2, and the electrical energy for 30 years is calculated.

In addition to uncertainty regarding the geothermal recovery factor, there is no site specific data from which to base an estimate of reservoir temperature (reservoir temperature is necessary to estimate wellhead thermal energy and the thermal utilization factor). Temperatures for these systems have been determined by analogy. An investigation of high temperature hydrothermal systems known to be associated with young silicic volcanic activity has revealed temperatures ranging from 176°C (61 y.b.p. rhyodacitic activity at Mt. Lassen volcano; Beall, 1981) to 271°C (.5-.8 m.y.p. rhyolitic activity at Roosevelt Hot Springs, Nevada; Benoit and Butler, 1983). Table 3.1 presents data relating age and type of volcanism to measured temperatures for several sites around the world. On the basis of Table 3.1, minimum, most likely, and maximum reservoir temperatures for "blind" systems have been estimated to be 200°, 230°, and 270°C, respectively. It should be noted that all of those systems in Table 3.1 with measured reservoir temperatures less than 200°C have maximum chemical geothermometers that predict reservoir temperatures in excess of 200°C.

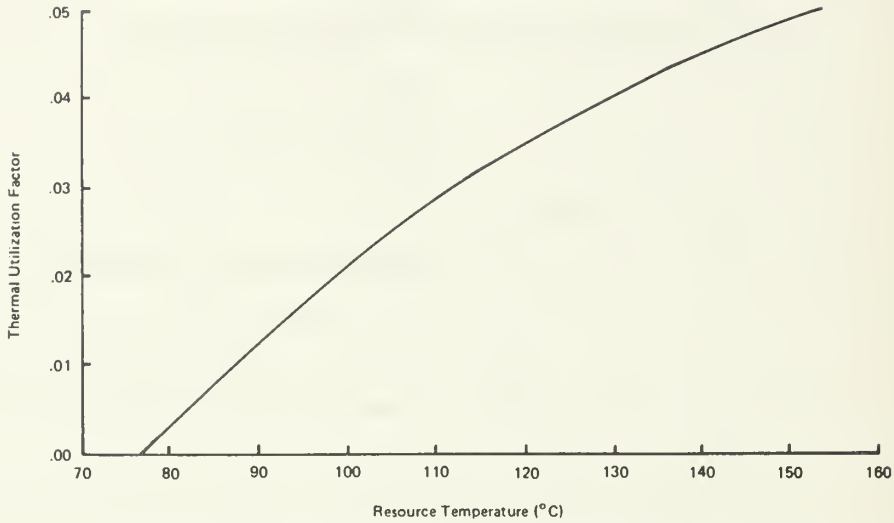

Figure 3.3 – Utilization factors for binary wellhead generators as a function of temperature. Electrical pumping losses have not been deducted (Ryan, 1983).

large. Additionally, it presupposes the existence of fluids in association with a pluton when in fact there is no direct evidence for the existence of such fluids.

Calculation of accessible resource base (Reservoir thermal energy column in Appendix 1) is based on the method of magmatic heat budget. The assumptions and limitations of the method as applied by Smith and Shaw (1975, 1979) have been discussed in a previous section.

For several of the sites listed in Appendix 1 there is insufficient data from which to make a quantitative estimate of geothermal potential. Such sites remain on the list of geothermal resource sites solely due to their proximity to young volcanism. They should be considered potential sites, yet understood that they may or may not have high level geothermal resources associated with them. This is particularly true for sites associated with young (less than 10,000 year old) basaltic volcanism (e.g., Diamond Craters in Harney County, Oregon). Smith and Shaw (1975) note that mafic volcanic systems probably do not form thermal anomalies of economic interest because they tend not to form magma chambers at depths of less than 10 km in the crust.

To summarize, most of the data presented in Appendix 1 for "blind" sites has been derived from the work of Smith et al., (1978) and Smith and Shaw (1975, 1979). The accessible resource base is assumed to be the heat remaining in the roof rocks above the intrusive. Minimum, most likely, and maximum reservoir temperatures are assumed to be 200°, 230°, and 270°C, respectively. Given the above assumptions, the methodology for determining electrical generation potential is the same as that utilized for high temperature hydrothermal convection systems.

It is interesting to note that Smith and Shaw (1975) feel that their estimates of thermal energy remaining in the ground (Q_n) are low, perhaps grossly low for those systems with long histories of magmatic injection that have not had comparable hydrothermal losses. As an example of the difference in the amount of thermal energy contained in an intrusive and an associated hydrothermal system, Smith et al., (1978) estimate that 240×10^{18} joules remain in the ground at Newberry Volcano, while Brook and others (1979) estimate that $27 \pm 10 \times 10^{18}$ joules are associated with the hydrothermal convection system at the same volcano.

3.3.4 Low Temperature Geothermal Resources

3.3.4.1 Introduction

Low-temperature geothermal resources are those with temperatures of less than 90°C. These temperatures are too low for the generation of electricity, but are suitable for many direct uses. In this report, a favorable direct use site is defined as one which possesses a fluid temperature at least 10°C above mean ambient air temperature, and is located within a specified distance of a heat load (see Chapters 2 and 9). Sites that do not have the capability to offset existing electrical loads are not evaluated. Here they are, however, included on the master list of sites for the region (see Exhibits I).

TABLE 3.1

Measured Temperatures in Geothermal Fields Associated With Young Volcanism

Country	Site	Type of Volcanism	Age of Volcanism	Measured Temperture (°C)	References
CANADA	Meager Creek	Rhyodacite	2550 y.b.p.	250	Fairbank et al. (1981)
EL DALVADOR	Ahuachapan	Andesite	Holocene	230	Romagnoli et al. (1975)
INDONESIA	Kamojang	Andesite	Active	236	Hochstein (1976) Grant (1979)
JAPAN	Hakone	Andesite	Active	140	Oki and Hirano (1970)
	Kirishima	Andesite	.8-1.5 m.y.b.p.	213	Taguchi and Hayashi (1983) Hayashi and Takagi (1983)
	Matsukawa	Andesite	Quaternary	200	Nakamura et al. (1970)
	Nigorikawa	Andesite	12,900 + 270 y.b.p.	192-272	Yoshida (1981) Ide (1982)
	Otake	Andesite	Active	205	Hayashida and Ezima (1982)
	Yunotani	Rhyolite	Recent	187	Parmenter and Hayashi (1981)
NICARAGUA	Momotombo	?	Active	200-325	Lopez et al. (1980)
PHILIPPINES	Tongonan	Andesite (?)	Active (?)	324	Studt (1979)
UNITED STATES	Coso	Basalt, Rhyolite	39,000 + 33,000 y.b.p.	213	Benoit and Butler (1983)
	Mt. Lassen	Rhyodacite	61 y.b.p.	176	Beall (1981)
	Long Valley	Rhyolite	450-720 y.b.p.	180	Sorey (1978)
	Newberry	Rhyolite	1350 y.b.p.	265	MacLeod and Sammel (1982)
	Roosevelt Hot Springs	Rhyolite	500,000-800,000 y.b.p.	271	Benoit and Butler (1983)
	Steamboat Springs	Rhyolite	1.14-3.00 m.y.b.p.	228	Silberman et al. (1979)

The terminology used for the evaluation of low temperature resources is identical to that used for high temperature resources. The **accessible resource base** is defined as all geothermal energy between the earth's surface and a specified depth in the crust, and the **resource** is that part of the accessible resource base that can be produced at the wellhead under reasonable assumptions of future economics and technology (Muffler and Cataldi, 1978). **Beneficial heat** is that part of the resource that is usable in a specific application. It is a function of the temperature drop within the application system (Reed, 1983b). In this study, only that portion of the beneficial heat which can be utilized for electrical offsets will be considered in the favorability analysis of individual sites.

The methodology used in this report is taken from USGS Circular 892, "Assessment of Low-Temperature Geothermal Resources of the United States - 1982." Circular 892 limits the use of accessible resource base to porous and permeable reservoirs that can produce water to carry thermal energy to the surface, reflecting the judgement of the authors that only low-temperature resources with high permeability will be economically competitive in the foreseeable future (Reed, 1983b). Thus a geothermal reservoir is a geometrically-defined volume of permeable rock from which thermal energy in water can be extracted.

3.3.4.2 General Methodology

The accessible resource base, resource, and beneficial heat values listed in Appendix 2 and summary tables of Exhibit II are calculated using the method of Sorey et al., (1983). The description of general and detailed methods is taken from the work of Sorey et al., (1983), except where otherwise noted.

Sorey et al., (1983) recognize two types of geothermal systems and two categories of low-temperature geothermal areas for each type of geothermal system. In hydrothermal convection systems, the upward circulation of water transports thermal energy to shallow depths. The two categories of hydrothermal convection systems are isolated springs and wells, and delineated reservoirs. For isolated springs and wells, the only evidence that a geothermal reservoir exists at depth is a single

spring or a group of closely spaced springs or a well that produces thermal water. Delineated reservoirs typically occur where thermal water moves upward along a fault and flows laterally into aquifers at relatively shallow depths (e.g., Klamath Falls, Oregon or Boise, Idaho).

In conduction-dominated systems, a high temperature gradient, usually resulting from a blanket of low thermal conductivity sediments, results in elevated temperatures in relatively shallow aquifers. The two categories of geothermal areas associated with conduction-dominated systems are sedimentary basins and coastal plains. No coastal plain type areas are present in the Pacific Northwest, and the only sedimentary basin type area that has been identified is associated with the Columbia Plateau Province of Oregon, Washington, and western Idaho (Mariner et al., 1983).

In general, the calculation of the accessible resource base is a straightforward application of the volume method of resource assessment, involving only the determination of reservoir temperature and reservoir volume. Reservoir temperatures and volumes are estimated by methods essentially identical to those described for high temperature hydrothermal systems. Where accurate estimates of reservoir volume cannot be made due to a lack of data, a standard reservoir volume of 1 km^3 is assumed. This assumption reflects the judgement of the authors of Circular 892 that 1 km^3 is the average volume of a system that supplies a few isolated springs or wells (Reed, 1983b).

The calculation of resource determines the amount of energy that can be recovered from the geothermal system over a period of 30 years without fluid injection into the reservoir. To accomplish the calculation, the number of evenly-spaced wells that can maintain production at a constant flow for a 30-year period with a maximum drawdown of 152 m (500 ft.) is estimated.

Beneficial heat is the amount of heat that a user is able to apply to a specific process. Whereas Brook et al., (1979) calculated beneficial heat as a fixed fraction of wellhead thermal energy, Sorey et al., (1983)

established an empirical relationship between temperature drops in direct use processes and reservoir temperature to calculate beneficial heat.

3.3.4.3 Detailed Methodology

3.3.4.3.1 Accessible Resource Base

The accessible resource base for each low temperature system analyzed in this study is calculated from the equation:

$$q_r = pc * a * d * (t - t_{ref})$$

where:

q_r = accessible resource base

pc = volumetric specific heat of rock plus water (2.6 $J/cm^3/^oC$)

a = reservoir area

d = reservoir thickness

t = reservoir temperature

t_{ref} = reference temperature

The value for pc (2.6 $J/cm^3/^oC$) is a weighted average based on rock types and porosities typical of low-temperature geothermal areas. The reference temperature is the mean annual surface temperature for the site. Circular 892 uses a standard reference temperature of 15°C for the entire United States, while this report uses the actual mean surface temperature at the site.

For reservoir area (a), thickness (d), and temperature (t), estimates of the minimum, most likely, and maximum values are made, permitting a calculation of the mean and the standard deviation for each parameter exactly as described in the section on high temperature methodology. The mean accessible resource base can then be calculated from the equation:

$$q_{avg} = pc * v_{avg} * (t_{avg} - t_{ref})$$

where:

v_{avg} = mean reservoir volume = $a_{avg} * d_{avg}$

As was the case with high temperature hydrothermal convection systems, Appendix 2 lists estimates of accessible resource base, resource, and beneficial heat calculated from both the mean and most likely values of the above parameters.

The determination of reservoir area is a function of the surface distribution of thermal springs and wells. Point sources or clusters of wells and springs distributed over an area of less than 4 km^2 are considered to be associated with an isolated hydrothermal convection system, and are assigned reservoir volumes of 1 km^3. This standard volume is based on minimum, most likely, and maximum volumes of 0.01, 1, and 2 km^3, respectively (Mariner et al., 1983). These estimates are reasonable, because, as stated by Mariner and others (1983), the assumption "probably overestimates the volume of reservoirs in granitic or other low-permeability rock in which the thermal fluids are restricted to narrow faults or fractures, but it underestimates the volume of isolated reservoirs in sedimentary and basin-fill terrains."

Groups of springs or wells which cover an area of greater than 4 km^3 are assumed to represent reservoirs with volumes of greater than 1 km^3. The mean reservoir thickness, unless there is data indicating otherwise, is assumed to be 0.25 km (based on minimum, most likely, and maximum permeable thicknesses of 0.1, 0.25, and 0.4 km, respectively) (Mariner et al., 1983).

The minimum, most likely, and maximum reservoir temperatures are estimated from a combination of measured temperatures in thermal springs and wells and calculated subsurface temperatures based on geothermometry. The mean temperature is considered to be characteristic of the entire reservoir, even though warmer and/or cooler temperatures probably occur locally within many reservoirs. For isolated systems, or systems with volumes only slightly in excess of 1 km^3, the minimum temperatures are measured temperatures, and the most likely and maximum temperatures are obtained from geothermometry calculations. For larger reservoirs the minimum, most likely, and maximum temperatures are generally measured in wells. For reservoirs for which there is inadequate chemical data or for which

the geothermometer temperatures are less than measured temperatures, the maximum and most likely temperatures are set equal to the spring or well temperature (Mariner et al., 1983).

The silica and Na-K-Ca geothermometers are most commonly used for estimating reservoir temperatures of low temperature systems. These geothermometers have been described in the section on high temperature hydrothermal systems. The maximum reservoir temperatures are usually based on the silica geothermometer assuming equilibrium with quartz. The most likely temperatures are usually based on either the Na-K-Ca geothermometer or the silica geothermometer assuming equilibrium with chalcedony. Where necessary the silica geothermometers are corrected for pH and the Na-K-Ca geothermometer is corrected for magnesium.

3.3.4.3.2 Resource

The resource is that part of the accessible resource base that can be produced at the wellhead under reasonable assumptions of future economics and technology (Muffler and Cataldi, 1978). The easiest method of determining resource is to multiply the accessible resource base for an area by a fixed recovery factor. Brook et al. (1979), and this study use a recovery factor (re) of .25 for intermediate and high temperature hydrothermal convection systems. The method employed by Sorey et al. (1983) involves an estimation of the number of wells that each reservoir can support over a development period of 30 years, assuming that cold water will not be injected into the reservoir. Sorey et al. (1983) consider that the lower reservoir areas and larger reservoir volumes associated with low temperature systems make injection schemes for enhanced energy recovery less likely than in high-temperature systems. It is recognized, however, that injection will be required in most low-temperature areas to alleviate environmental problems.

Resource is calculated from the formula:

$$q_{WH} = (pc)_f * N * Q * P (t - t_{ref})$$

where:

q_{WH} = resource

$(pc)_f$ = volumetric specific heat of fluid (4.1 $J/cm^3/^oC$)

N = number of production wells

Q = average volumetric discharge of each production well

P = development period

t = wellhead fluid temperature (assumed to be equal to the reservoir temperature)

t_{ref} = reference temperature = mean annual surface temperature

Sorey et al. (1983) assume a production plan consisting of a square grid of regularly-spaced wells discharging at 31.5 L/s (500 gpm) for 30 years with a cumulative drawdown at the center of the production field of 152 m (500 ft.). The specific drawdown applies to a decline in water level in a well or a decrease in wellhead pressure corresponding to a decline of 152 m in the piezometric surface for a flowing well.

Given the above production plan:

$$N = a/a_w$$

where:

a = reservoir area

a_w = area per well = square of distance between adjacent wells

The calculation of optimum well spacing is affected by several reservoir parameters including reservoir area, transmissivity, and compressibility (both reservoir and fluid compressibility). A detailed discussion of the effects of these parameters on optimum well spacing can be found in Sorey et al. (1983). The result is the generation of two sets of curves (Figures 3.4 and 3.5) (taken from Sorey et al. 1983) that relate optimum area for each well (a_w) to reservoir area and transmissivity. One set of curves applies to reservoirs with impermeable confining beds and the other applies to reservoirs with

leaky confining beds. Optimum well spacings are significantly smaller for reservoirs with leaky confining beds than for reservoirs with impermeable confining beds. From the value of a_W determined from the curves, N can be calculated.

A source of uncertainty in the above method for calculating resource is the assumption that permeable conditions exist throughout the reservoir. It is not certain that an entire resource area is sufficiently permeable to produce fluid at rates near those assumed in the development program. Therefore, to adjust for non-uniform transmissibility, including non-productive areas within the reservoir, Sorey et al., (1983) introduce a constant, k, such that:

$$N = k * (a/a_W)$$

The minimum, most likely, and maximum values for k are 0.0, 0.5, and 1.0, respectively. The inclusion of the factor k tends to decrease estimates of the number of wells that each reservoir can support, and the estimates of resource (and beneficial heat) are therefore more conservative.

The recovery factor is defined as the ratio q_{WH}/q_R. Due to the method of analysis, the number of wells that each reservoir can support does not increase in proportion to the reservoir area. As reservoir area increases, optimum area per well increases due to drawdown interference between wells. Thus large area reservoirs have considerably lower recovery factors than small area reservoirs. However, as reservoir area decreases, the induced recharge of colder water from surrounding regions becomes more important and the breakthrough of cold water into production zones rather than drawdown interference may limit recovery factors. To allow for this, Sorey et al. (1983) limit the recovery factor to a maximum value of 0.25. The recovery factor for low temperature systems is listed in Appendix 2.

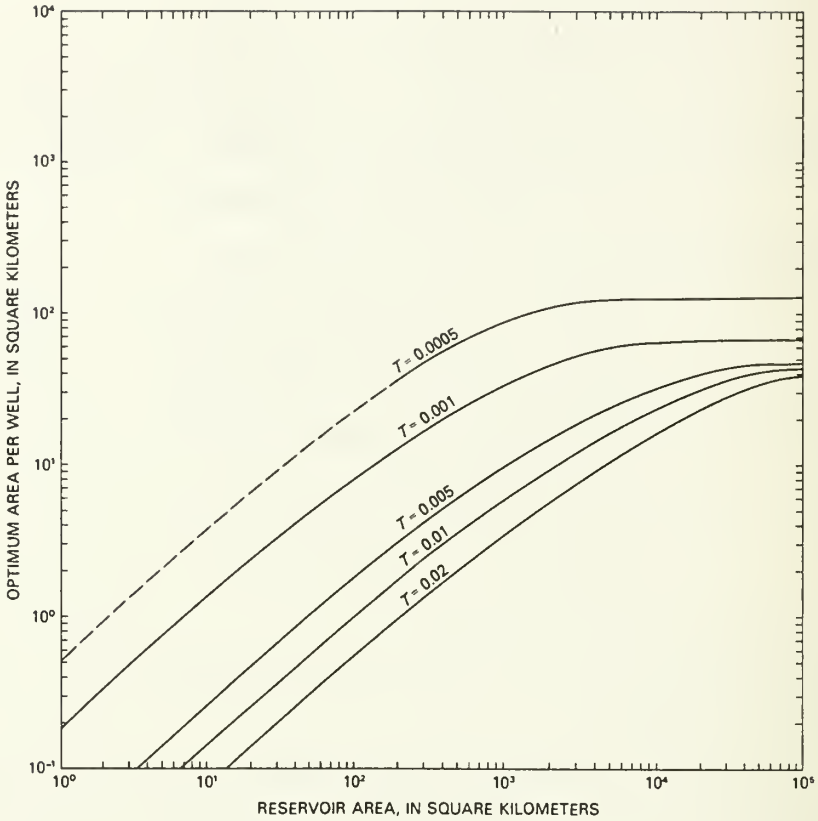

Figure 3.4 — Reservoir area a versus optimum area per well a_w for reservoirs with leaky confining beds, based on a production plan involving evenly spaced wells producing for 30 years at 31.5 L/s with a cumulative drawdown of 152 m. T, reservoir transmissivity (in square meters per second); dashed portion of curve for T=0.0005 m^2/s involves fewer than five wells to produce the allowable drawdown. Drawdown computations were based on a reservoir storage coefficient S of 10^{-4} and a value for the product of hydraulic conductivity and specific storage KS_s of $6 \times 10^{-16} s^{-1}$ for each of two confining beds.

There are several other factors which may be important in the determination of resource. The lateral boundary conditions of small reservoirs may be important. Sorey et al. (1983) assume that these boundaries connect the reservoir to additional areas of permeable rock. It is possible, however, that in some reservoirs the boundaries are either impermeable or act as constant pressure sources. In the first case, the value of a_W should be adjusted upward, and in the second it should be adjusted downward. These adjustments have not been made for the data of this report because reservoir boundaries have not been adequately tested in most geothermal areas.

A second important factor occurs in reservoirs whose areal configuration is elongate rather than square. Here, estimates of a_W based on a square grid which encompasses the same total area give too conservative estimates of the optimum well spacing. Allowances must be made in some of these cases for the greater distances between

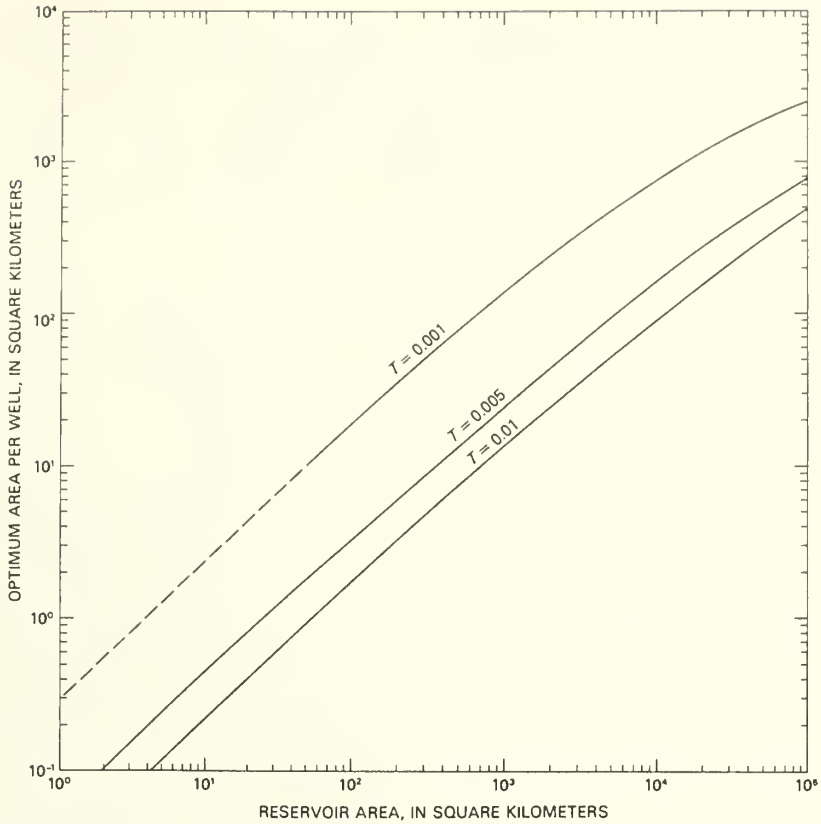

Figure 3.5 – Reservoir area a versus the optimum area per well a_w for reservoirs with nonleaky confining beds, based on a production plan involving evenly spaced wells producing for 30 years at 31.5 L/s with a cumulative drawdown of 152 m. T, reservoir transmissivity (in square meters per second); dashed portion of curve for T=0.001 m^2/s involves fewer than five wells to produce allowable drawdown. Drawdown computations were based on a reservoir storage coefficient S of 10^{-4} and a value for the product of hydraulic conductivity and specific storage KS_s of 0 for each of two confining beds.

production wells and the center of the reservoir which implies less interference between wells. For some reservoirs in sedimentary basins Sorey et al. (1983) adjusted the values of a_W downward by a factor of two to account for the above effects.

A final consideration concerns the method of assessment used in Circular 892. The magnitude of geothermal resource estimates are dependent upon an assumed development period of 30 years and the assumption of constant development rate for each well. Larger resource estimates would be obtained for each area if longer development times were assumed. This is true because the development scheme used by Sorey et al. (1983) is dependent on drawdown, and the rate of drawdown in the reservoir decreases with time. Depending on reservoir size, the rate of drawdown at each well becomes very small after a few years, so that at longer times total drawdown is mainly a function of the number of wells and the discharge

rate per well. Therefore, the well spacing and number of wells that yield a total drawdown of 152 m would not be significantly different for periods of development longer than or shorter than 30 years, and larger resource estimates would be obtained if longer development periods were assumed.

For those low-temperature resource areas which possess standard volumes of 1 km^3, the resource is calculated by assuming a flat recovery factor of 25 percent. The resource for reservoirs with volumes larger than the standard volume is estimated using the methods discussed above. For most reservoirs, the existence of leaky confining beds can be inferred, but measured transmissivity values are unavailable. Transmissivity has been estimated mainly on the basis of the discharge rates of thermal springs and wells. Systems with springs or wells that individually discharge less than 3.3 L/s are assigned a transmissivity of 0.0025 M^2/s, those with individual spring or well discharges of a few hundred to a few thousand liters per minute are assigned a transmissivity of 0.005 M^2/s, and systems with springs or wells with greater discharges are assigned a transmissivity of 0.01 M^2/s. A few systems with wells having very large discharges are assigned a transmissivity of 0.02 M^2/s (Mariner et al. (1983).

3.3.4.3.3 Beneficial Heat

Beneficial heat is the amount of energy that a user is able to apply to a specific process (Nathenson and Muffler, 1975). The mean beneficial heat is calculated from the equation:

$$q_{ben} = (pc)f * (k*a/a_w) * Q * P * t$$

where:

q_{ben} = mean beneficial heat with units of thermal energy

$(pc)f$ = volumetric specific heat of water

$(k*a/a_w)$ = mean number of wells that the reservoir can support

Q = average volumetric discharge of each production well

P = development period

t = temperature drop that occurs as energy is extracted in some process (°C)

Sorey et al. (1983) have established an empirical relationship between mean reservoir temperature (t) and the temperature drop occurring in a direct use application (t) such that:

$$t = 0.6 * (t - 25^{o})$$

The 25°C on the right side of the above equation is based on the nationwide average value for mean annual surface temperature of 15°C, plus the 10°C needed for a spring or well at the surface to be considered a resource. For use in a local area, the above equation must be modified to take into account the local mean annual surface temperature.

3.3.4.4 Summary

Low-temperature geothermal resources are defined as those with reservoir temperatures of less that 90°C. These resources are further restricted to the upper 10 km of the earth's crust and by the criteria that the temperature gradient in the resource area must be at least 25°C/km and that the reservoir be permeable. Only those sites capable of offsetting electrical loads are evaluated in this report.

The accessible resource base is calculated using the volume method of assessment. Low-temperature resources associated with isolated springs or wells are assigned a standard volume of 1 km^3. The calculation of resources is based on a production model of equally spaced wells in a square grid producing at 31.5 L/s for a 30-year period with a cumulative drawdown of 152 m at the center of the field. No injection into the reservoir is assumed, though natural recharge into the reservoir as a result of declines in reservoir pressure is allowed. Using this method of calculation the fraction of the accessible resource base that can be recovered at the wellhead in 30 years varies from 25 percent for small area reservoirs to 0.1 percent for regional aquifers in large sedimentary basins. Beneficial heat is estimated using an

empirical relationship established between temperature drops in direct use applications and reservoir temperature.

3.4 Cascade Range and Basin and Range Province Estimates

3.4.1 Introduction

There are special problems associated with the evaluation of geothermal resources in both the Cascade Range and the Basin and Range physiographic provinces. In the Basin and Range Province concerns revolve around the fact that fault-controlled systems are dynamic rather than static systems. These concerns apply to geothermal systems in other provinces as well. In the Cascade Range Province, problems arise from the lack of surface thermal phenomena in a province that has undergone nearly continuous volcanism for the last several million years. The few Cascade hot springs that exist are not particularly attractive geothermal targets. However, continuing volcanism (Mt. St. Helens erupted in May, 1980) may imply the presence of a significant resource.

The next section discusses the patterns of heat flow in the Cascade Range of Oregon and Washington, and the interpretation of that heat flow pattern. An attempt to evaluate the accessible resource base for the entire range follows. Finally, various types of geothermal sites present in the Cascade Range and the criteria used to select them are described.

The discussion of Basin and Range problems focuses on a more empirical approach to the nature of Basin and Range hydrothermal systems, and the problems involved with evaluating their geothermal resources.

3.4.2 Cascade Range

3.4.2.1 Introduction

The Cascade Range trends essentially north-south from British Columbia, Canada, to northern California. The Oregon and southern Washington portion of the range can be separated into two physiographic provinces. The High Cascade Province, which lies east of the Western Cascades and includes the prominent composite volcanic cones which characterize the Cascade Range, is composed primarily of Pliocene (approximately 2-5 m.y.b.p.) to Holocene (less than 10,000 y.b.p.) lava flows. The Western

Cascades are composed of Oligocene (approximately 24-77 m.y.b.p.) to upper Miocene (approximately 5-11 m.y.b.p.) flows, epiclastic deposits, and pyroclastic rocks. The Northern Cascades in Washington differ slightly, being composed primarily of Mesozoic and Paleozoic rocks upon which some Holocene composite volcanoes sit (e.g., Mt. Baker). A broad alluvium-filled structural depression, the Puget Lowland in Washington and the Willamette Valley in Oregon, borders the western edge of the range.

3.4.2.2 Cascade Range Heat Flow

Heat flow in the Cascade Range has been described most completely for the central Oregon portion of the range (Blackwell et al., 1978; Blackwell et al., 1982; Black et al., 1982; Black, 1983; Blackwell and Steele, 1983). There, the most striking feature of the regional heat flow pattern is a rapid increase from values on the order of 40 mW/m^2 in the Willamette Valley and Western Cascade provinces, to values of greater than 100 mW/m^2 in the eastern part of the Western Cascade and the High Cascade Provinces (Figure 3.6). The transition from lower to higher heat flow is very narrow, averaging less than 10 km in width throughout most of its length in Oregon. This transition occurs approximately 10 km west of the mean physiographic boundary between the High Cascades and Western Cascades.

In the Cascade Range of southern Oregon data are somewhat sparser. There are almost no regional data within or east of the transition. A detailed heat flow study of Crater Lake, however, has found an average heat flow for the lake of 140 mW/m^2 (Williams and Von Herzen, 1983). This high heat flow tends to support the concept of higher heat flow east of the transition zone, but it also should be noted that "spot" anomalies of high heat flow are commonly associated with Holocene Cascade Range volcanos.

In southern Washington the pattern of heat flow is nearly identical to that in central Oregon. The magnitude of the heat flow high, however, is not as large. North of the Clackamas River in Oregon the nature of the transition zone changes. Although the relative position of the transition remains intact, the amplitude of the variation is lower, ranging from

about 30 mW/m^2 on the west to 80 mW/m^2 on the east. For this portion of the Cascade Range in Oregon and Washington, heat flow values in excess of 100 mW/m^2 are found only in "spot," or local anomalies associated with young composite volcanoes making up the High Cascade peaks. The change in heat flow patterns which occurs at the Clackamas River also corresponds to a marked decrease in the volume of young quaternary basaltic volcanism north of the Clackamas River (Priest, 1982; Priest et al., 1983).

Heat flow data in central and northern Washington is very sparse, and much more work is needed. The data that do exist tend to support the idea of a rapid transition from lower to higher heat flow. It is not known whether the large eastward bulge in the contours of Figure 3.6 in central Washington is real or not (Blackwell and Steele, 1983b).

3.4.2.3 Heat Flow Interpretation

The heat flow data discussed above have been interpreted by Blackwell et al. (1982) to result from the subduction of the Juan de Fuca plate beneath the Pacific Northwest. This model of the surface heat flow data requires the presence of a large heat source, which may be at least partially molten, at depths of 7 to 10 km beneath the central portion of the Cascade Range. The width of the heat source is 40-60 km (Blackwell and Steele, 1983b). Figure 3.7 shows geothermal gradient, heat flow, interpreted crustal temperature, and Bouguer gravity for the western part of the central Oregon Cascade Range. Blackwell and Steele (1983b) cite other heat flow evidence from Washington and British Columbia that suggests that the heat source is at similar depths in both the northern and southern portions of the Cascade Range. The temperature in the northern (Washington) would, however, have to be significantly lower than at similar depths in the southern (Oregon) portion of the range. Blackwell and Steele (1983b) suggest that the mean temperature at a depth of 10 km would be on the order of 500° to $600^{o}C$ in the north, compared to a temperature of 700° to $800^{o}C$ in the south.

Other geophysical studies tend to support or are at least permissive of a large, possibly partially molten heat source at depth beneath the Cascades: (1) There is a series of sharp -25 mgal gravity anomalies

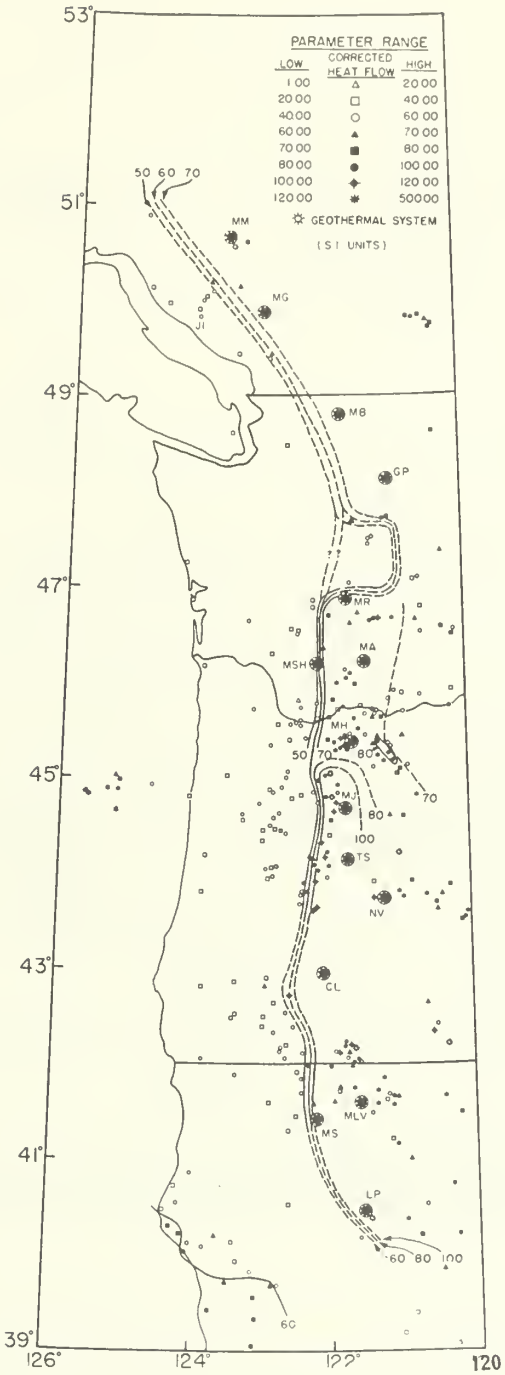

Figure 3.6 – Heat flow map of the Cascade Range and adjoining areas (Blackwell and Steele, 1983b).

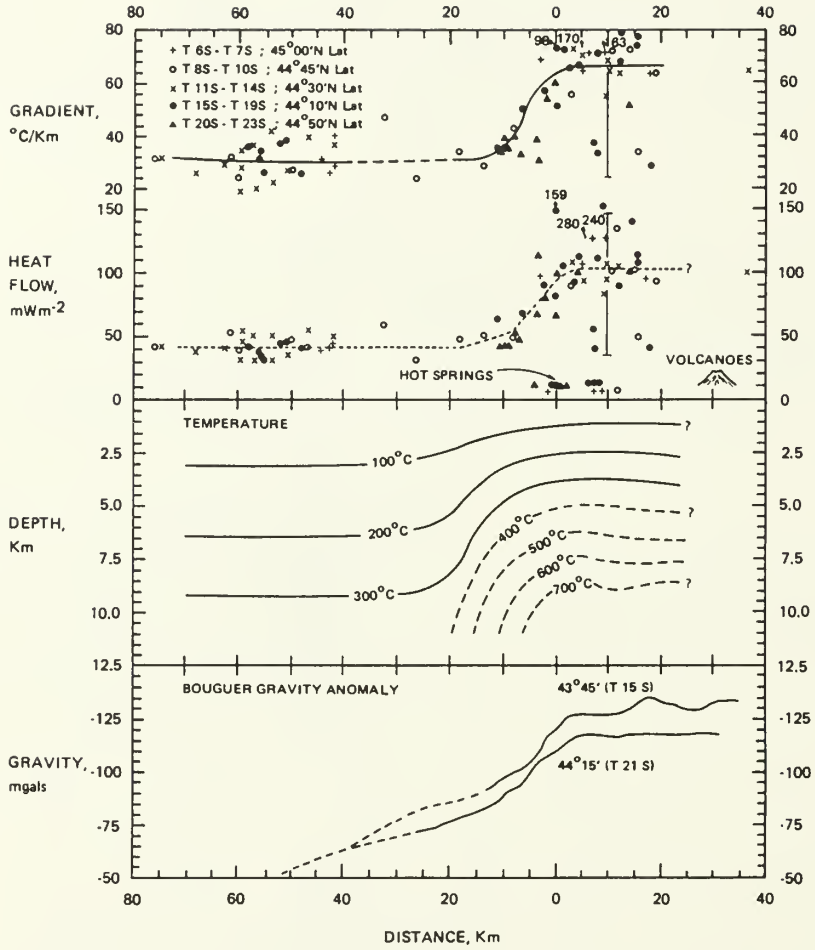

Figure 3.7 – Geothermal gradient, heat flow, interpreted crustal temperatures, and regional Bouguer gravity for the western part of the northern Oregon Cascade Range (gravity data are from Couch and Baker, 1977). Heat-flow data between latitudes 43° 15'N. and 45°05'N. are projected onto the profile. The zero distance reference is the 100-mW/m² heat-flow contour line (see Plate 7) (modified from Priest and Vogt, 1982).

(Figure 3.7) which correspond closely to the heat flow transition in the central Oregon Cascades. Couch et al. (1982a) interpret the gravity anomalies to indicate the presence of a large fracture system that extends from the Columbia River into northern California. Geologic mapping (Priest and Woller, 1983; Woller and Black, 1983) has identified north-south trending down-to-the-east faults in the vicinity of the gravity anomalies. Blackwell et al. (1982), however, show that on theoretical grounds, the -25 mgal anomalies could be at least partially due to high temperature, partially molten rock at depth.

Curie Point depth analysis, assuming a Curie Point of 580°C, has resulted in a calculated depth to the Curie Point of between 6-9 km in the central

Oregon Cascades. Calculations of theoretical heat flow and temperature gradients based on a 6-9 km Curie Point depth agree closely with Cascade heat flow observations (Connard, 1979).

A magnetotelluric profile, normal to the Cascade Range, was completed in the vicinity of Waldo Lake as part of a regional survey of the entire Cascade Range (Stanley, 1982). The survey identified a deep crustal conductor lying at a depth of between 10 and 15 km beneath the High Cascades. The crustal conductor occurs over most of the western United States, especially in areas of high geothermal flux (Stanley, 1982). Although it is not necessary to have partially molten deep crustal or mantle rocks to produce the resistivities observed in the deep conductor (Stanley, 1982), a partial melting hypothesis remains possible based upon magnetotelluric data.

Teleseismic P-residual studies in the Oregon Cascades identified a zone of relatively low velocity in the crust and upper mantle beneath the High Cascades (Iyer et al., 1982). The authors interpreted the results as indicating the presence of low-density, high-temperature rock to great depths. An analysis of Pn wave travel times beneath the Oregon Cascades (Ganoe, 1983) reached the same conclusion. Neither study was able,

however, to identify discreet magma bodies. Therefore, if there is a zone of partially molten rock beneath the Oregon Cascades, the magma probably occurs in pockets too small to be identified by the teleseismic P-residual technique.

In summary, a transition from low heat flow in the Willamette Valley-Puget Lowland Provinces of Oregon and Washington to high heat flow in the Cascade Range Province is interpreted as the result of subduction of the Juan de Fuca plate beneath the northwestern United States. The low heat flow zone is caused by the subducting slab, which acts as a heat sink until it reaches depths of 100 to 150 km, while the high heat flow zone is due to magmatic processes which generate a magmatic arc. Thermal modeling of the high heat flow anomaly indicates the presence of high temperatures (700°-800°C), perhaps partially molten material at depths of around 10 km in the central Oregon Cascades, and 500°-600°C material at similar depths in the Washington Cascades (Blackwell and Steele, 1983b).

3.4.2.4 Geothermal Potential of the Cascades

The prospects for exploitation of geothermal resources in the Cascade Range are promising. The heat flow transition zone appears to result from regional crustal movements rather than local upper crustal movements, and temperature modeling (Figure 3.7) indicates the possibility of a zone of partial melting at a depth of about 10 km in the central Oregon Cascades (Blackwell et al., 1978, 1982). The regional temperature gradient east of this transition zone is 66°C/km (Figure 3.7), so that circulation of groundwater to depths of 5 km could produce temperatures of approximately 300°C.

Inasmuch as volcanic arcs create major geothermal provinces, and are already the sites of power-generating facilities elsewhere, it is likely that the Cascade Range possesses significant potential for the generation of electricity from geothermal fluids. One problem, however, is the absence of evidence of large, high-temperature hydrothermal systems in the High Cascade Range. This lack of surface manifestations may be due to the masking effect of cold groundwater in permeable young volcanic rocks. Alternatively, the relatively low levels of seismicity in the Pacific

Northwest may be responsible for the lack of surface manifestations. Hot springs are leakage phenomena, and they require vertical permeability in order to penetrate through cold aquifers and reach the surface. The relative aseismicity of the northwest may maintain secondary subsurface seals which eliminate vertical permeability (LaFleur, 1983). A third possibility is that there is insufficient heat stored in the shallow parts of the volcanic carapaces of the large composite volcanoes to significantly heat up the groundwater (Blackwell et al., 1982). Whatever the reason, a lack of surface manifestations does not necessarily imply the nonexistence of geothermal resources. In the Western Cascades Province, where thermal conditions prior to 6 m.y.b.p. were probably similar to those of the High Cascades today (Blackwell et al., 1982), there is ample evidence of hydrothermal circulation associated with exposed plutons and surrounding large areas of altered country rock (Peck et al., 1964). Using oxygen-isotope data, Taylor (1971) found evidence of extensive interaction of shallow magma chambers with groundwater systems. This evidence of an extinct volcanic arc so closely related to the modern active volcanic arc suggests the presence of similar systems beneath the High Cascades.

Further evidence for the existence of high-temperature geothermal systems beneath the High Cascades comes from deep drill holes at three localities. In the Meager Mountain Geothermal Area, located in an extension of the Cascade Range in British Columbia, Canada, drill hole M7 encountered a bottom-hole temperature of 202°C at a depth of 367m. The temperature gradient at the bottom of the hole was 330°C/km (Fairbanks et al., 1981). At Newberry Volcano, located in the central portion of the Oregon Cascades, a 930m hole completed by the USGS in 1981 encountered a bottom-hole temperature of 265°C (Sammel, 1981a). A hole drilled by Sandia National Laboratories approximately 460m southeast of the USGS hole encountered temperatures in excess of 158°C at depths of 350 to 424m. The temperature of the main fluid entry was probably in excess of 170°C (Black et al., 1984). Since drilling these holes, Newberry Volcano has become one of the main focuses of high temperature geothermal exploration in the Pacific Northwest. Finally, at Mt. Lassen, in the Cascade Range of northern California, drill hole Walker "O" No. 1, encountered a temperature of 176°C at a depth of 610 m. In

this hole, there was a reversal in the temperature-depth curve below 731 m, and the bottom hole temperature was 124°C at a depth of 1,222 m (Beall, 1981). These four holes clearly demonstrate the presence of temperatures adequate for the generation of electrical energy beneath the High Cascades at major volcanic centers. A confirmation of high temperatures beneath the Cascade chain as a whole must await the completion of a deep (2-3- km) drill hole in the High Cascade province between the major volcanic vents.

3.4.2.5 Accessible Resource Base

The accessible resource base is defined as the amount of geothermal energy contained in a specified volume of rock at a specified temperature referenced to mean annual surface temperature (Brook et al., 1979). Using the volume method of resource assessment, the accessible resource base is calculated from the formula:

$$q_R = pc * a * d * (t - t_{ref})$$

where:

- q_R = accessible resource base
- pc = volumetric specific heat of rock plus water (assumed to be 2.7 $J/cm^3/°C$; Brook and others, 1979)
- a = reservoir area
- d = reservoir thickness
- t = reservoir temperature
- t_{ref} = reference temperature (15°C, Brook and others, 1979)

Table 3.2 presents the calculations of accessible resource base for the Oregon and Washington Cascade Range. Several assumptions are involved in the construction of the table. First, it was assumed that a minimum temperature of 150°C is required for the generation of electrical energy. Secondly, the maximum depth from which geothermal fluids can be recovered is 3 km. The first assumption is conservative, as it ignores generation schemes that can generate electricity from temperatures less than 150°C. The second is more valid, as 3 km is the approximate

TABLE 3.2

Estimate of the Accessible Resource Base in the Oregon and Washington Cascades

	Area (km^2)	Volume (km^3)	Mean Reservoir Temperature (°C)	Accessible Resource Base ($X10^8J$)	Electrical Energy (MWe for 30 Years)
	NORTH OF CLACKAMAS RIVER				
MINIMUM	17,200	8,600	165°	3,480	45,680
MAXIMUM	25,800	12,900	165°	5,220	68,520
	SOUTH OF CLACKAMAS RIVER				
MINIMUM	14,000	17,500	190°	8,280	139,268
MAXIMUM	21,000	26,250	190°	12,400	208,900
	TOTAL				
MINIMUM	-	-	-	11,750	184,948
MAXIMUM	-	-	-	17,620	277,420

maximum depth of production wells drilled in various geothermal areas around the world (Brook et al., 1979). A further assumption is that crustal temperature models of Blackwell et al. (1982) (Figure 3.7) are correct and that the temperature at a depth of 10 km is 800°C in the central Oregon Cascades and 600°C north of the Clackamas River (Blackwell and Steele, 1983b).

To simplify resource evaluation, the Cascade Range was divided into two segments at the Clackamas River. Minimum and maximum estimates were calculated in both areas assuming a width of the crustal heat source of 40 km and 60 km, respectively (Blackwell and Steele, 1983b). North of the Clackamas River, the depth to the 150°C isotherm is 2.5 km and the temperature at 3 km is approximately 180°C, yielding a mean reservoir temperature of 165°C and a reservoir thickness of .5 km. South of the Clackamas River the depth to the 150°C isotherm is 1.75 km and the temperature at 3 km is approximately 230°C, yielding a mean reservoir temperature of 190°C and a reservoir thickness of 1.25 km (Figure 3.7).

The estimates of Table 3.2 assume that the entire Cascade Range between the California and British Columbia border is underlain by a resource between 40 and 60 km in width. Calculations of electrical energy are included only to emphasize the magnitude of the high temperature geothermal resource associated with the Cascade Range. They have been calculated with W_a/q_R ratios derived from Figure 3.1 and thermal utilization factors derived from Figure 3.2 assuming an optimized single flash conversion technology. Some areas definitely not available for geothermal development (e.g., Wilderness Areas and National Parks) are included in the estimates.

A comparison of Table 3.2 with a similar table (Table 7.1) from Black (1983) reveals that the maximum estimate of Table 3.2 for the area south of the Clackamas River is considerably less than Estimate 1 from Table 7.1 ($12{,}400 \times 10^{18}$ J as opposed to $16{,}985 \times 10^{18}$ J, respectively). The methodology used in both instances is identical. The discrepancy is due to differing assumptions about the width of the heat source.

Assuming that there is a vast amount of heat energy contained beneath the Cascade Range, no one could argue that it is possible to convert the entire accessible resource base into electrical energy. The following section discusses criteria used to select specific sites in the Cascades which would appear to have some potential for development.

3.4.2.6 Cascade Range High Temperature Sites

There are four "categories" of sites identified in Appendix 1: (1) hydrothermal convection systems, (2) "blind" or igneous related systems (3) fault-related systems, and (4) sites related to geophysical anomalies.

There are 15 thermal springs in the Oregon Cascade Range with temperatures above 20°C. Most are concentrated in deep valleys along the eastern edge of the Western Cascade province. Based on an examination of chemical geothermometers, only eight of these springs and one additional spring in Washington (Mt. Baker Hot Spring) have potential reservoir temperatures in excess of 90°C. Other high temperature springs in Washington are located in national parks or wilderness areas. The evaluation of resources associated with these hydrothermal systems is a straightforward application of the volume method which has been described previously. Five sites in the Oregon Cascades and three in the Washington Cascades are "blind," or igneous-related sites. The methodology used in evaluating these sites, and the criteria for their recognition in Appendix 1 have been described in a previous section.

Table 7.1 of Black et al. (1983b) has given estimates of the electrical generation potential of the Oregon Cascade Range south of the Clackamas River. Table 7.1 gives a "worst case" estimate for the central Oregon Cascades of 2,485 MWe (as compared to an estimate of 401,760 MWe for the entire accessible resource base). In that "worst case" estimate, permeability is assumed to be present only as fracture permeability in a 100m-wide zone associated with north-south trending lineations. The total length of north-south lineations is derived from the studies of Venkatakrishnan et al. (1980) and Kienle et al. (1981). The 100m width was an arbitrary value based on observations of north-trending faults in the Belknap Hot Spring and Cougar Reservoir areas of the central Cascades. North-south lineations were used because they

were judged to have the highest probability of remaining open in the state of essentially north-south compression that exists in the Cascades at the present time (Venkatakrishnan et al., 1980).

One site in Linn County, Oregon, is listed in Appendix 1 as a "Generic HC Fault System." The location of the site is based on the criteria discussed above. The calculation of electrical generation potential, however, is based on standard default volumes rather than the method used in the construction of Table 7.1 of Black et al. (1983) (i.e., reservoir volume = .1 * fault length * 1.25 km). Many sites of this type are present in the Cascade Range. Black et al. (1983) calculated 1,775 km of essentially north-south lineations in the Oregon Cascades south of the Clackamas River and east of the transition to higher heat flow. Not all of these lineations represent viable geothermal sites, as not all of the lineations can be expected to be faults, and not all faults have moved recently enough to possess open fracture permeability. The estimate in Appendix 1 does serve, however, to indicate the magnitude of the resource that might be associated with a High Cascade fault system with significant fracture permeability.

Two additional very large areas were selected as sites in the central Oregon Cascades on the basis of shallow depths to the Curie Point isotherm. These sites, the Crater Lake area in Klamath County, Oregon, and the Mt. McLoughlin area in Jackson County, Oregon, possess estimated depths to the Curie Point isotherm of 5-7 km and 4-6 km, respectively (Connard, 1979; Connard et al., 1983; McLain, 1981). Reservoir areas for these sites were based on the area of the associated geophysical anomaly. Reservoir thicknesses and temperatures were based of the crustal temperature model of Figure 3.7. The evaluation methodology was the standard volume method described in sections 3.2.3 and 3.3.2. Similar sites were not selected north of the Clackamas River due to the lower magnitude of the heat flow high, and the relative lack of detailed geophysical data.

One additional site, the Shukash Basin in Deschutes County, Oregon, was delineated on the basis of an associated large negative residual gravity anomaly. It has been thought that this anomaly might represent a

gravity expression of a large collapsed caldera. No resource estimate was completed for the site, however, because no other corroborating evidence for the presence of a resource could be found. The Shukash Basin has, however, remained on the list as a potential site.

3.4.3 Basin and Range

The volume method of resource assessment (see section 3.2.3) used for most of the sites in this report assumes that geothermal reservoirs are essentially static storage systems consisting of discreet volumes of porous rock. Flowthrough is allowed in the system, but it is assumed that most production is from reservoir storage. The process of resource assessment is one of estimating the percentage of this stored energy that can be extracted. All that is needed for a relatively accurate evaluation of the magnitude of a geothermal resource is a method of determining reservoir volume, an estimate of reservoir porosity (15 percent is used in USGS Circular 790 and this report), a fluid production model (e.g., the "sweep" process is used in this report), and some assumptions regarding the efficiency with which thermal energy in the reservoir can be converted into useful energy at the surface.

The above model for a geothermal reservoir is valid for some areas. The classic example in the United States is the Imperial Valley of southern California. The model is not valid, however, for systems occurring in the Basin and Range Province. Basin and Range systems are associated with the large range-bounding faults typical of the province. They are "liquid dominated dynamic flow systems transporting thermal energy from deeper levels to the shallow subsurface and to the surface" (Yeamans, 1983). The production zones are not discreet volumes of porous rock, but rather consist of high permeability faults and fractures separated by blocks of impermeable rock. The effective porosity of production zones may be as low as 1-2 percent of the total thermal anomaly defined by exploration drilling (Yeamans, 1983).

Yeamans (1983) divides Basin and Range hydrothermal systems into four components: (1) The recharge zone is the area where recharge water enters the subsurface, (2) flow paths are the subsurface pathways that the fluids

follow on their journey from the recharge to the discharge zone, (3) the depth of circulation refers to the depth of water circulation required to obtain the maximum temperature observed in the system, and (4) the discharge zone represents the channels and flow paths of upflow from the deepest depth of circulation.

Detailed isotopic studies have shown that the fluid in active geothermal systems is meteoric water. The water enters the system in the recharge zone, descends to depths of several kilometers, is heated by the regional geothermal gradient as it does, and rises to the surface at the discharge zone. The fluid flow in the system is driven by a combination of mechanical energy derived from the difference in head between the recharge and discharge zones, and the thermal energy resulting from the differences in density between hot and cold waters. The minimum depth of circulation of the fluids can be estimated from:

$$D = (T_s - T_r)/g$$

where:

D = depth of circulation

T_s = maximum temperature in system, predicted from geothermometers

T_r = surface temperature of recharge water, generally taken as mean annual surface temperature

g = regional temperature gradient

Maximum depths of circulation are not known.

The discharge zones are the best known parts of these systems. The discharge zone consists of discrete upflow conduits separated by large volumes of impermeable or relatively impermeable rock with low or nonexistent porosity. As most of the fluids in the system are located at great depths below the discharge zone, production does not come from storage in the shallow part of the discharge zone. Production wells drilled in the discharge zone cause a pressure decline, and the pressure decline causes

increased flow up the outflow conduits until equilibrium is achieved with the new discharge rate. The fluid produced from the system comes from a combination of compression of the system and expansion as system pressures decline. The system is not dewatered (Yeamans, 1983). Because these systems are dynamic systems, the yield is determined by the transmissivity of the production zone. That is, the production rate and pressure decline resulting from production will be governed by the least transmissive section along the fault zone flow path (Yeamans, 1983).

This discussion emphasizes that the volume method of resource assessment does a poor job evaluating the magnitude of a Basin and Range geothermal prospect. To quote Yeamans (1983):

> Hydrothermal systems are dynamic flow systems with relatively limited reservoir capacity. Thus in evaluating the development potential, the amount of energy stored in the systems is not as important as the rate at which energy can be extracted from the relatively shallow discharge zone. Because Basin and Range hydrothermal systems are flow systems and not reservoir systems, petroleum engineering techniques for reservoir analysis are inappropriate and large-scale development of and production from a Basin and Range hydrothermal system depends on the unknown transmissive characteristics of the deeper parts of the system.

The considerations discussed above are particularly important in the Basin and Range Province because the extentional tectonics of that province keep open high permeability conduits (i.e., the range-bounding normal faults). The same arguments also apply wherever a hydrothermal system is fault-controlled. This is especially true in the Cascade Range, where known hydrothermal systems appear to be controlled by essentially north-south trending normal faults. The present state of north-south compression in the Cascades helps maintain high permeability in the fault zones. As in the Basin and Range Province, the volume method of assessment may not provide an accurate measure of the geothermal potential of a specific site. It is, however, the only method of assessment available to us where drillhole data is lacking.

CHAPTER 4

Legal and Institutional Issues

4.0 AN ANALYSIS OF THE LEGAL AND INSTITUTIONAL FRAMEWORK AND HOW IT MAY BE IMPROVED

4.1 Introduction

The legal and institutional aspects of geothermal development generally have been addressed by the United States Congress and by the legislatures of each of the states in the Bonneville Power Administration (BPA) region. The conclusions reached, and the direction given by these bodies, have been, however, significantly different. Too often the legal and institutional framework established by these legislative bodies has left as many questions unanswered as answered, or created as many new problems as it resolved. In some unfortunate cases, the legislation enacted has proven to be more an obstacle to development than an aid.

A review of the legal and institutional framework within which geothermal resources will be developed necessarily must begin with a thorough discussion of leasing at both the state and federal levels, and how conflicts of ownership and leasing can result from differences in how state and federal governments define and characterize geothermal resources. Leasing questions will be followed by a discussion of groundwater law and how conflicting uses can affect development. And, finally, jurisdiction over development, production, and use will be considered.

Such a review of the established legal and institutional framework will allow for a careful evaluation of factors which are having or could have serious impacts upon the development and utilization of the region's geothermal resources and should give insight into how these issues can be resolved.

4.2 Leasing Considerations

Leasing provides geothermal developers with access and a priority right to carry out exploration and development activities.

The development of statutes for the regulation of geothermal leasing in the United States began with the passage of the California Geothermal Resources Act in 1967 and the Federal Geothermal Steam Act in 1970. The states of Idaho, Montana, Oregon, and Washington followed suit during the 1970's, and often modeled their statutes upon either the California or Federal statutes. However,

a number of state leasing statutes differ considerably from the California and federal models. This divergence is due to the complexity of dealing with the resource, and/or to historical differences in how different states have dealt with the disposition and protection of natural resources.

The major differences and a source of many of the problems affecting leasing can be traced to how geothermal resources are defined and characterized, and how ownership rights are assigned for purposes of leasing.

4.2.1 Resource Definition

Geothermal resources are related to water, gas, and minerals, to both the surface and subsurface estates, and to both water rights and mineral titles. How geothermal resources are defined affects other resource definitions as well as all aspects of regulation.

Legislative bodies are faced with two basic tasks in defining geothermal resources. The first task is to describe the physical properties that distinguish geothermal resources from other natural resources and thus clearly establish ownership and what is subject to geothermal leasing, taxation, and development regulations. Secondly, legislative bodies must relate geothermal resources to groundwater, subsurface minerals, and other established resources. An ideal resource definition should be both anticipative and retrospective, i.e., it should look forward to future leases, exploration, and development activities while, at the same time, look backward in order to place geothermal resources into the framework of leases, reservations, and property titles inherited from the past (Sacarto, 1976).

How well legislation accomplishes these two tasks has a profound influence upon minimizing conflicts of ownership and, of course, upon the development of leasing procedures.

The California Geothermal Resources Act of 1967 made the first attempt to define geothermal resources:

> 'Geothermal resources' shall mean the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in,

resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, or other hydrocarbon substances (ACPRC § 3700).

The Federal Geothermal Steam Act of 1970 (Public Law 91-581) defined geothermal resources thusly:

> 'Geothermal steam and associated geothermal resources' means (i) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; (ii) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any by products derived from them (30 USC 1001).

The federal definition defined byproduct so as to exclude oil, hydrocarbon gas, and helium.

Both the California and the federal definitions provide detailed descriptions of the physical properties which distinguish geothermal resources from other natural resources, but fail to relate geothermal to groundwater and minerals.

Washington took a somewhat different approach in 1979 to defining geothermal resources:

> 'Geothermal resource' means only that natural heat energy of the earth from which it is **technologically practical to produce electricity commercially** and the medium by which such heat energy is extracted from the earth, including liquids or gases, as well as any minerals contained in any natural or injected fluids, brines, and associated gas, but excluding oil, hydrocarbon gas, and other hydrocarbon substances (RCW 79.76.). (Emphasis added.)

The principal difference in the Washington definition is that it restricts geothermal resources to those **"from which it is technologically practical to produce electricity commercially."**

The Oregon definition, which, for the most part, is based on the federal model, provides additional restrictions based upon temperature and depth[1]. Hot water from wells less than 600 M (2,000 ft.) and with bottom-hole temperatures less than 120°C (250°F), must be developed according to state water law. It is not necessary, however, under Oregon law to know the bottom-hole temperature of wells before they are drilled as all geothermal prospecting is regulated under geothermal statutes. However, if a **water well** should, in the course of development, encounter temperatures approaching 120°C (250°F), a geothermal permit must be obtained (Justus, et al., 1980).

The state of Idaho has defined geothermal resource to mean "the natural heat energy of the earth, the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat." (IC § 42-4002)

The Montana state lands leasing statute defines geothermal much the same as does Idaho, and reads as follows:

> 'Geothermal resources' means the natural heat energy of the earth, including the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth, either present in, resulting from, created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from the material medium of any geothermal resource (RCM § 81-2602).

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1 All geothermal wells, regardless of depth, higher than 250°F bottom hole temperature, must be drilled according to geothermal statutes. All wells deeper than 600 m (2,000 ft.) must be developed according to geothermal statutes.

In all of the above examples, the definition accomplishes the task of describing the physical properties that distinguish geothermal resources from other natural resources, but generally fail to characterize geothermal resources in relation to groundwater, subsurface minerals, and other established resources.

The failure to so characterize geothermal resources makes the establishment of ownership difficult and has led to conflicts with owners of other resources.

4.2.2 Resource Characterization

As the legal definitions recognize, geothermal resources are similar in many respects to water, minerals, and gas. The result has been considerable disagreement--including litigation--over the essential nature of the resource and corresponding ownership rights. Such a climate of uncertainty has impeded geothermal development, and made resource characterization a major issue which must be dealt with in order to ensure that geothermal exploration and development can proceed in a timely fashion.

The federal government, in passage of the Geothermal Steam Act of 1970, avoided the question of how geothermal resources should be characterized. The Steam Act chose instead to direct the Justice Department to bring suit to quit title to geothermal resource ownership. The courts were asked to decide whether or not geothermal resources had been reserved to the federal government as part of the mineral estate. The action brought by the Justice Department (United States of America vs Union Oil Company of California) began in 1971, and a verdict in favor of the United States was not reached until October 1977 under the title Ottobonie vs the United States of America. This delay resulted in a moratorium on leasing all lands patented under the Stock Raising Homestead Act of 1916 until the case was decided. It resulted in a loss of considerable revenue to the United States, as well as slowing development by several years in prime areas such as The Geysers in Northern California. The delay and problems of lost revenue could have been avoided if Congress in passing The Geothermal Steam Act of 1970 had simply characterized the resources as mineral and, therefore, belonging to the owner of the mineral estate. The California Legislature, in the passage of the California Geothermal Resources Act of 1967, also

avoided this very important question, and again it was left up to the courts to decide the issue and to characterize the resource. It wasn't until the case Pariani vs California was decided in 1981 (California Court of Appeals, 1981) that geothermal was declared to be a mineral resource for purposes of ownership and leasing of lands in California.

Like California and the federal government, the state of Oregon has also avoided the question of characterization. The other states in the BPA region, however, have chosen to characterize geothermal resources. However, they have not done so in a manner which has resulted in a clear understanding of ownership or leasing rights.

In Washington, the legislature declared that "notwithstanding any other provision of law, geothermal resources are found and hereby determined to be *sui generis*, being neither a mineral resource nor a water resource" (Bloomquist, et al., 1980).

In Idaho, the state declared that geothermal resources are...*sui generis*, being neither a mineral resource nor a water resource, but...closely related to, and possibly affecting and affected by, water and mineral resources in many instances (Renwick and Lewis, 1976).

Montana, like Idaho and Washington, has adopted the *sui generis* characterization, but other Montana statutes lead to the conclusion that geothermal resources are considered to be water (Perlmutter, 1978).

The *sui generis* characterization of geothermal resources serves only to cloud the ownership issue and is, for all practical purposes, meaningless because it fails to clearly characterize the resource and therefore does not clarify the question of ownership.

Whether geothermal resources are characterized as water or mineral, it is best to have such a solution explicitly legislated so that ownership can be clearly determined. In three court decisions, geothermal resources have been determined to be part of the mineral estate (supporting the concept of geothermal resources as an energy fuel). It is therefore desirable, especially in view of the court decisions, that state legislatures carefully evaluate

whether legislation characterizing geothermal as a mineral resource should be introduced. If introduced, such legislation should also recognize the dynamic nature of a geothermal system and the critical importance of water to the extraction of the heat energy.

It is evident that the characterization of the resource accomplishes the second task and allows for the placement of geothermal resources into a framework of historical leasing, reservation, and property titles.

4.2.3 Ownership

By clearly defining geothermal resources to be either water or mineral, the problems associated with the establishment of ownership could be greatly reduced.

Mineral ownership derives from an estate in land, which may be 'severed' from property rights to the overlying surface. Groundwater in the west is generally held to be in the public domain. Where geothermal resources have been determined to be *sui generis*, the state may assign ownership of the resource to the owner of the surface estate or the mineral estate, or may, in fact, claim the ownership of all geothermal resources in the state regardless of ownership of the surface or mineral estate, and separate from existing water rights.

The federal government claims geothermal ownership wherever it holds the mineral estate, either jointly with the surface estate or as a mineral reservation where the estates have been severed. This claim was upheld in the (Ottobonie vs U.S.) case mentioned earlier. Whether federal ownership extends to groundwater useful for thermal purposes when estates are severed is unclear. The states have primary control over water resources pursuant to the establishment of a federal enclave.

The states have taken a number of differing approaches to the assignment of ownership, reflecting how resources are characterized as water, mineral, or *sui generis*.

Washington has declared geothermal resources to be the property of the surface owner (Bloomquist, et al., 1980), but it is presently unclear, because

of the impractical way in which the state has defined geothermal resources, what is truly included in this assignment, and what remains available for appropriation as groundwater. The state claims ownership of all groundwater underlying state and school lands. In order to gain access to low temperature geothermal resources below these lands, a commercial lease would have to be obtained. It is likely that the assignment of geothermal resources to the surface owner in Washington will result in a number of court challenges by those who have maintained an interest in the mineral estate when estates have been severed. Ironically, the state of Washington is one of the largest owners of mineral rights on lands where the mineral and surface estates have been severed.

In Idaho, the state claims ownership of all geothermal resources underlying state and school lands. However, state lands are those in which the state of Idaho owns either the surface rights, the mineral rights, or both (Idaho, 1978). The situation is made even more complex because certain specific types of geothermal resource utilization are excluded from geothermal resource permit requirements, as can be seen from the following:

> No person operating or proposing to operate a geothermally heated greenhouse, hothouse, swimming pool, hot spring bath, or hot water fish propagation facility, space heating plant or similar facility unless such operation is in conjunction with a geothermal resource use not specified in this subdivision, shall be compelled to comply with the geothermal resource permit requirements under this act if such person obtains a valid water right permit for such operation (Idaho Code § 4003).

Thus, the ownership question is complicated in Idaho and, as has been stated, "although many low temperature uses do not require a valid geothermal permit, such operations can acquire one" (McClain 1979). Likewise, high temperature geothermal operations developed in Idaho as an energy source, a mineral resource, or a material medium do not require a valid water right permit, but such operations can acquire such a permit. A prudent operator would be wise in obtaining both permits for additional protection from third party intervention and to avoid potential conflicts with state agencies. A problem with applying for both permits is that performance bonds, and applications fees, are required for each. The elimination of duplicate requirements should be carefully considered.

Montana statutes involving ownership of geothermal resources are as unclear as those of Idaho. Section 81-2602(1) of Title 81 of the Montana law as it relates to the management of state-owned lands states:

> "No right to seek, obtain, or use geothermal resources has passed or shall pass with any existing or further lease of state or school lands" (Perlmutter, 1979). Perlmutter continues "Thus, at least with respect to the leasing of state lands, it is clear that geothermal rights are reserved, unless included explicitly within a geothermal lease. However, the question remains open with respect to lands which have been sold by the state, or is proposed for sale." Are geothermal rights included in the mineral reservation, or do they pass with ownership of the surface? The final sentence of 81-2602(1) just quoted lends weight to the contention that geothermal resources are included in general mineral rights...however, the declaration in Section 81-2602(1) are neither a mineral nor a water resource leads us to the opposite conclusion..."

While it may seem reasonable to assume that the same definition applies, in general, to private lands in Montana, the final sentence dealing with state leases will not apply. Thus, with respect to private lands, we are left with the *"sui generis"* statement, and consequently, have little guidance for the resolution of disputes between surface and subsurface owners.

Montana's water laws also apply to all geothermal development involving production and diversion of geothermal fluids. "Geothermal Water" is, in fact, included in the Montana Water Use Act definition of water, although geothermal is not defined. Thus, as in Idaho, regardless of ownership, the developer of geothermal resources would be best advised to secure the necessary water rights.

The state of Oregon in the Oregon Geothermal Resources Act of 1975 grants geothermal ownership rights to the surface owner. The Act states:

> Ownership rights to geothermal resources shall be in the owner to the surface property underlain by the geothermal resources unless such rights have been otherwise reserved or conveyed. However, nothing in this section shall divest the people or the state of any rights, title, or interest they may have in geothermal resources (ORS 522.035).

It is unclear what the latter part of this section means in terms of ownership due to the failure of the legislature to characterize the resource so that ownership can be clearly assigned.

Summarizing the situation, it is extremely important that geothermal resources be defined so as to be easily distinguishable from other natural resources so that a clear assignment to an estate can be accomplished and ownership determined. Although ownership questions could be settled by the courts, a legislative approach would be much preferred to avoid the serious delays which have occurred in deciding ownership questions by the courts in California and at the federal level.

4.2.4 Resource Access

Providing reasonable access and priority rights to public lands for geothermal exploration and development is crucial if geothermal resources are to become an important additional energy resource.

There are a number of ways private developers can be provided access to public resources. Resource rights may be simply applied for and conveyed at little or no charge, e.g., federal mining claims and non-competitive oil and gas leases, or made available through competitive bidding procedures (Sacarto, 1976).

Competitive bidding can be in the form of cash bonuses, annual rentals, production royalties, profit shares, or work commitments. Regardless whether resource rights are transferred by competitive or noncompetitive means, developers may be required to pay annual rentals, production royalties, and diligently explore for and develop the resource.

Access is provided through procedures including exploration or prospecting permits and/or noncompetitive leases for lands of unknown potential to requiring competitive bidding for particularly valuable resource areas. Another approach is to allow for exploration and prospecting permits, while requiring that all leasing be by competitive bid (see Table 4.1).

TABLE 4.1-Geothermal Exploration Permits

	Manner Awarded Non-Exclusive	Term Negotiated	Conversion Privilege	Annual Rental
Federal	By application	Variable	No	None
Idaho	None	NA	NA	NA
Montana	None	NA	NA	NA
Oregon	By application	Non-exclusive 1 year Renewable	No	None
Washington*	None	NA	NA	NA

*In draft, no regulations have been adopted.

NA = Not Applicable.

TABLE 4.2 - Leasing

	Non KGRA Lands		KGRA Lands	
	Newly Offered	Application Overlap	Competitive Bidding Factor	Leasing Designation Criterion
Federal	By application	Competitive	Cash bonus	Discovery, geology, or competitive interest
Idaho	By application	Public auction	Cash bonus	Discovery, geology, or competitive interest
Montana	Competitive	Competitive	Cash bonus	All lands are awarded competitively
Oregon	By application	Public drawing	Cash bonus and public drawing	Discovery, geology, or competitive interest
Washington*	Competitive	Competitive	Cash bonus	All lands are awarded competitively

*In draft, no regulations have been adopted.

The federal government has adopted a three tiered approach to providing access to public lands. Prospecting permits, the first tier (Table 4.1), are available to developers and allow for geological, geochemical, and geophysical surveys, as well as the drilling of holes to a depth of 900 m (3,000 feet). These permits are non-exclusive and are not convertible to leases. Non-competitive leases are the second tier (Table 4.2), and are available on lands of unknown potential to the first qualified applicant.

Competitive leases, the third tier (Table 4.2), are available in Known Geothermal Resource Areas, or KGRAs* to the highest qualified bidder. A noncompetitive lease application can, however, be rejected at anytime up to when the lease is issued if the area is declared a KGRA by the Bureau of Land Management. Legislation considered by the 98th Congress, as well as the 96th and 97th Congresses, would if enacted protect the standing of a lease application in the case where an area was reclassified as a KGRA before leases are issued. This provision is extremely important because it allows an applicant to undertake exploration activities without the risk that success could cause him to lose his rights to a noncompetitive lease. Although attempts to pass legislation containing this provision have been unsuccessful to date, it is expected that amendments to the Geothermal Steam Act of 1970 will be introduced into the 99th Congress (Freihofer, 1984).

Competitive bidding for KGRA lands is by cash bonus bidding only. However, legislation considered by the 98th Congress (Senate Bill S 558) (United States Senate, 1983) called for a percentage of all KGRA lands to be offered on other than a cash bonus basis--namely royalty bidding. Non-cash bonus bidding allows small companies and utilities to equitably compete for leases because no large outlays of money are required up-front. Although this legislation did not pass, it is expected to be reintroduced in 1985 (Freihofer, 1984).

The states in the BPA region also have adopted the two or three tiered access system (see Tables 4.1 and 4.2). Oregon has statutory provisions for the issuance of exploration or prospecting permits in addition to having both competitive and noncompetitive leases available. Oregon, in addition to

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* KGRA is defined as "an area in which the geology, nearby discoveries, competitive interest, or other indications would, in the opinion of the Secretary of the Interior engender a belief in men who are experienced in the subject matter that the prospects for extracting of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose," United States Geological Survey, 1979.

competitive cash bonus bidding, provides for simultaneous filing of noncompetitive applications with the successful qualified applicant selected by random public drawing (Oregon Administrative Rules Chapter 141).

Washington and Montana lease all lands through a competitive bidding process (Sacarto, 1976; Washington, 1982). In Montana, however, if only one person or company bids for the tract offered, an applicant may negotiate a lease with the Department of Natural Resources and Conservation. The Department may, however, choose to reject all bids and applications (Perlmutter and Birkby, 1980). Washington has under consideration a leasing system based upon the Montana model that would allow for the negotiation of a lease if no bids are received. Idaho employs a two tiered leasing system with noncompetitive leases being available to the first qualified applicant. Lands within KGRAs are leased through public auction on a cash bonus basis.

Careful consideration should be given to several factors when evaluating the mechanisms used to transfer public resources.

The system should provide for **multiple forms** of access. Exclusive or non-exclusive exploration or prospecting permits can effectively attract developers to wildcat areas. Such permits can be even more effective in encouraging exploration if developers are given preference to convert a permit to a noncompetitive lease or the right to match the highest bid if the leases are awarded through competitive bidding.

Noncompetitive leases provide a mechanism by which developers can secure rights to a resource with little cash outlay, and are extremely important in attracting developers to unproven areas. The filing of a noncompetitive lease application should provide protection for the applicant against reclassification of the area as a KGRA before the lease is granted. Such protection can guarantee that the applicant will be granted a lease on a noncompetitive basis if work performed by the applicant results in the reclassification and/or the applicant can be given the right to match the highest bid if the reclassification is the result of work performed by another applicant. Legislation which was considered by the 98th Congress (United States Senate, 1983), would provide these forms of protection to federal lease applicants. Although neither Senate Bill S 558 or S 883 was passed in

1983, the legislation is expected to be reintroduced into the 99th Congress (Freihofer, 1984).

Although competitive leasing results in the greatest initial monetary benefit to the public, it can discourage or prevent certain developers (e.g., public utilities) from gaining access to public lands. This is most detrimental where leases are offered only on a competitive basis such as in Washington and Montana. For example, the lower economic value of low to moderate temperature resources (less than 150°C) seldom warrants large outlays of money, and may result in many areas not receiving bids. This severely inhibits exploration and development in these areas if the state is unwilling to negotiate a lease with an applicant. Competitive leasing can also provide great difficulties for public bodies which cannot expend large sums of money on high risk ventures. This is a problem for public entities because they must obtain approval of expenditures through a public forum, which provides other bidders advance knowledge of bids which are to be submitted.

Several possible solutions to these problems exist. First, competitive areas might be limited to those areas where a significant high temperature discovery has been made so that the value of the resource may be accurately determined by both the lessor and potential lessees. Legislation considered by the Congress would limit KGRAs to areas where there is physical evidence of the existence of geothermal resources capable of generating electricity (Senate Bill S 558, Sec. 3 United States Senate, 1983). It is important that such areas be limited to those possessing high temperature resources capable of being utilized to generate electricity as the economic value of resources for direct applications seldom can justify the additional expenditures and risk required by competitive bidding. Earlier legislation of this type failed to gain passage, but is expected to be reintroduced in 1985 (Freihofer, 1984).

Second, the use of non-cash bonus bidding, i.e., royalties or profit sharing, allows for maximum return to the public without tying up needed exploration dollars for cash bonuses. This also allows for full participation by public entities.

Third, work commitments instead of cash bonuses or royalty bids can speed development by freeing needed capital for exploration activities, but will not provide maximum return to the public from the exploitation of public resources if not tied to royalties or profit-sharing. (Work commitments are agreements made by the potential lessee to conduct exploration activities at a specified rate, including drilling of temperature gradient and deep exploration wells.)

Fourth, cash bonus bidding can be employed and still allows for public utility participation if the bidding system requires that sealed bids be submitted by private developers in advance of bids by public entities. This allows public bodies a period of time for gaining approval of the expenditure of funds through the public process. This, however, assumes that there is no other prohibition against the use of such funds by the public entities involved.

Fifth, a mechanism should be provided for reclassifying KGRA lands which have been offered but which have received no bid. Senate Bill S 558, Sec. 4, considered by the 98th Congress (United States Senate 1983), would have allowed this on federal lands, and although S 558 did not pass, similar legislation is expected to be reintroduced (Freihofer, 1984).

4.2.5 Acreage Limitations

The federal government has set limits on the size of leases and limitations upon holdings in any one state (see Table 4.3). The Geothermal Steam Act of 1970 limited lease size to a maximum of 1,036 hectares (2,560 acres) with a minimum of 260 hectares (640 acres). In addition, the Steam Act limits individual holdings to 8,290 hectares (20,480 acres) per state (United States, 1970).

Lease size limitations on state-controlled lands have been established by the states of Idaho, Montana, Oregon, and Washington (see Table 4.3). In most cases, the minimum size has been set at 16 hectares (40 acres), while maximums ranges from 260 to 1,036 hectares (640 to 2,560 acres) and above. Idaho has limited the holding of leases to a maximum 50 townships and ranges (Sacarto, 1976), and also has set a minimum lease size of 16 hectares (40 acres) and a maximum of 260 hectares (640 acres). Oregon, Washington, and Montana have all set the minimum lease size at 16 hectares (40 acres),

but none has established a maximum number of acres which can be held. Oregon, unlike Washington and Montana, has not set a maximum lease size.

Setting limits on minimum lease size has drawn criticism from small developers of low temperature resources. The minimum limits require tying up a great deal of acreage with accompanying rentals, for applications of geothermal energy which often can be successfully undertaken on less acreage.

The maximum lease size on state lands, generally 260 hectares (640 acres), appears to be of little consequence, although if a sizeable application fee is required per application, the 260 hectare (640 acre) maximum could result in a financial burden on a large-scale development because of the total number of applications which would have to be filed.

On the other hand, the federal limitation upon individual holdings in a given state has been singled out by developers as the most serious impediment to geothermal development in the United States. Developers contend that the 8,230 hectare (20,480 acre) limitation imposed by the federal government severely handicaps the successful operator since an average of two discoveries in a state effectively eliminates a company from additional exploration. Because of this, once a skilled group of technical personnel are trained, there are insufficient resources to allow them to continue an orderly progression of exploration and development. The limitation has, in addition, forced many companies at or near the acreage limitation to give up attractive prospects because other prospects were identified which they felt deserved a higher priority than acreage already held.

The U.S. Congress considered legislation during the 98th Congress (Senate Bills S 558 and S 883) which would have raised the acreage limitation to 20,700 hectare (51,200 acres) per state, and exempt from this limitation any leases under development (United States Senate, 1983). Although this legislation did not pass, it is expected to be reintroduced in 1985 (Freihofer, 1984). There is alsoa strong possibility that the Secretary of Interior will raise the acreage limitation to 20,700 hectares (51,200 acres) through administrative changes made possible by the Geothemal Steam Act 1970. An exemption of acreage under development from the limitation would

TABLE 4.3 - Geothermal Lease Provisions

	Annual Rental	Royalties	Acreage Limits
Federal	Non-competitive First 5 year $1/acre Year 6-15 $3/acre Competitive First 5 year $2/acre Year 6-15 $4/acre/yr.	Primary: 10-15% Direct use: 10-15% Byproduct: 5% Minimum: 2.00/acre/yr.	Min. lease: 640 acres Max. lease: 2,560 acres Max. state holding per individual or company: 20,480 acres
Idaho	Non-competitive First 5 years $1/acre Second 5 years $2/acre Thereafter $3/acre	Primary: 10% Direct use: Byproduct: 5% Minimum:	Min. lease: 40 acres Max. lease: 640 acres Max. state holding per individual or company: interest in 50 townships -and- ranges
Montana	Non-competitive Minimum $1/acre Negotiated in lease	Primary: Min. 10% Direct use: 10% Byproduct: 2-5% Shut in: set in lease Min. $2/acre/year	Min. lease: 40 acres Max. lease: 640 acres Max. state holding per individual or company: None
Oregon	Non-Competitive Year 1-3 $1/acre Year 4 $3/acre Year 5-10 $5/acre Years renewed $5/acre	Primary: 10% Direct use: Byproduct: 5% Minimum:	Min. lease: 40 acres Max. lease: None Max. state holding per individual or company: None
Washington*	Non-competitive First 2 years $20/acre Year 3 $15/acre Year 4 $20/acre Year 5 $25/acre	Primary: 10% Direct use: variable Byproduct: 5% Min.: 2.50/acre/year	Min. lease: 40 acres Max. lease: 640 acres Max. state holding per individual or company: none

*In draft, no regulations have been adopted.

TABLE 4.3
(Continued)

	Primary Term	Renewal	Renegotiation of Rentals & Royalties
Federal	10 years 5 year extension possible if drilling or have sales contract	So long as commercial production occurs 40 year maximum preferential right to second 40 year term	Secretary of the Interior may readjust the rentals and royalty on any geothermal lease issued under the Geothermal Steam Act at not less than 20 year intervals beginning 35 years after the date geothermal steam is produced
Idaho	10 years	So long as commercial production occurs or drilling continues to min. 1,000 ft. 40 year maximum and primary renewable preferential right	Renegotiation of rentals and royalties 40 years after and of primary terms and 40 years thereafter
Montana	10 years Can be extended so long as drilling proceeds	For duration of production	Terms may be adjusted every 20 years beginning 35 years after production of geothermal steam. The maximum increase for any single adjustment is 50 percent, with an overall maximum royalty of 22½ percent.
Oregon	10 years 5 year extension possible if prior to commercial production	So long as commercial production occurs, successive 10 year periods up to 50 year maximum. Right to first refusal to second lease term	Rentals 5 per acre per year. Royalty net subject to change.
Washington*	20 years	Preference right to lessee for second 20 year term.	Not subject to renegotiation original terms prevail for like of lease.

*In draft, no regulations have been adopted.

appear to provide for industry's desire to have an even greater acreage allowance than the 20,700 hectares (51,200 acres), without creating a problem by having too much acreage tied up which is not under development.

4.2.6 Rentals and Royalties

Annual lease rentals are normally assessed for the opportunity to explore on public lands and serve primarily to cover the cost of regulation and administration. Rentals may also provide the lessor with a tool for ensuring diligent exploration because required expenditures on exploration must equal a set amount or increased rentals will be assessed.

Rentals on federal and state lands shown in Table 4.3 usually begin at $1 per acre per year. The minimum rental on federal KGRA lands is $2 per acre per year.

On federal lands, the rental increases to $3 per acre, beginning with the sixth year, but with the provision that expenditures on exploration may be deducted from the increased amount. Exploration expenditures, in order to qualify, must equal $4 per acre in year six, $6 per acre in year seven, and $8 per acre in year eight, $10 per acre in year nine, and $12 per acre in years 10 through 15.

The states of Oregon, Washington, and Idaho have also adopted increasing rentals as a means of encouraging diligent exploration.

Royalties are assessed on production and ensure that some portion of the value of the public resource is returned to the public treasury.

Royalties, unlike cash bonuses and rentals, involve no risk to the developer and, therefore, appear to treat equitably both large and small developers as well as public and private entities. However, the manner in which royalties are calculated may significantly penalize a developer engaged in the direct utilization of geothermal resources in comparison to developers of electrical generation projects. Although royalties on both electrical and direct use products range from 10-15 percent for state as well as federal leases (see Table 4.3), the way in which a royalty is calculated can and does make a

significant difference in the amount different developers will pay. In the case of electrical generation, the royalty is based upon the selling price of the steam or electricity. On direct use projects, the royalty is theoretically based upon the value of the heat energy available as determined by the cost of equivalent fuels, i.e., well head gas or mine mouth coal. However, if a direct use project involves the sale of energy, the royalty is based on gross sales.

The following example clearly illustrates how differences in royalty calculations can seriously affect the economic viability of direct use projects. If developer 'A' leases and develops a geothermal resource on federal lands and sells the energy to user 'B', the 10 percent federal royalty is assessed against gross sales. If, on the other hand, the developer and the user are the same entity, and no sale takes place, then the royalty is based on the equivalent cost of the cheapest conventional fuel in the area. The royalty is then inflated at the same inflation rate as that of the conventional fuel. If the lessee happens to be a corporation in a 48 percent effective federal income tax bracket, the royalty would be subtracted from sales and reduce the company's tax liability by 48 percent of the royalty. The net effect would be a 5.2 percent royalty. If the royalty is assessed against a non-taxable entity such as a public utility or a municipal heating district, it can become one of the major annual costs of the geothermal project. For example, the Klamath Falls, Oregon, Business Core Heating District is projected to pay itself back in seven years. If it were necessary to drill the production wells on federal lands and pay a 10 percent royalty on the energy consumed, this same project would suffer a $3,600 per year loss for the first 10 years in terms of annual equivalent costs. If the annual cost of operating the Klamath Falls system included a federal royalty of 10 percent, the breakdown of the annual costs for the first year of operation would be as follows: (Higbee, 1979)

	Percent
Electrical pumping costs	24.8
Maintenance costs	19.7
Federal royalty payments	55.5

The inequity of royalties levied on developers of direct use geothermal energy has resulted in legislation being introduced into the U.S. Congress

that would lower the royalty on such projects from the present 10 to 15 percent to 5 to 10 percent. The same legislation would allow the Secretary of the Interior to "defer royalty payments for non-electric geothermal developments when it is deemed to be in the public interest, for municipal, cooperative, or other political subdivisions lessees where legal limitations on front-end financing otherwise would prohibit or significantly deter development" (United States Senate, 1983).

However, the deferring of royalty payments and reductions in the percentage do not solve the problems associated with the way in which a royalty is calculated. A possible solution to this problem is, however, under consideration by the Washington State Department of Natural Resources (see Table 4.4) (Washington Department of Natural Resources, 1982). The method of calculation encourages full use of the resource by rewarding the developer who utilizes more Btus per unit of resource with a lower royalty per Btu. The system should also result in a greater return to the state treasury because even at the lower royalty, the full use of the available Btu's will result in a higher total payment.

The system under consideration in Washington deserves a thorough evaluation at both the state and federal levels. If it is adopted it could have a substantial impact upon the number of direct use projects which could be undertaken on state and federal lands.

TABLE 4.4 - PRICING OF DIRECT USE LOW TEMPERATURE GEOTHERMAL ENERGY ($ PER 1,000 GALLONS)

	DISCHARGE TEMPERATURE - DEGREES FARENHEIT																						**
T	270°	260°	250°	240°	230°	220°	210°	200°	190°	180°	170°	160°	150°	140°	130°	120°	110°	100°	90°	80°	70°	* T	Base Price $/1,000 Gal.
10	$.073	$.068	$.065	$.061	$.058	$.055	$.053	$.050	$.048	$.046	$.044	$.042	$.040	$.039	$.037	$.035	$.034	$.033	$.031	$.030	$.029	10	0.458
20	.146	.137	.129	.122	.116	.110	.105	.100	.096	.092	.088	.084	.080	.077	.074	.071	.068	.065	.063	.060	.058	20	0.917
30		.205	.194	.183	.174	.166	.158	.151	.144	.137	.132	.126	.121	.116	.111	.106	.102	.098	.094	.090	.086	30	1.375
40			.258	.245	.232	.221	.210	.201	.192	.183	.175	.168	.161	.154	.148	.142	.136	.130	.125	.120	.115	40	1.833
50				.306	.290	.276	.263	.251	.240	.229	.219	.210	.201	.193	.185	.177	.170	.163	.156	.150	.144	50	2.292
60					.348	.331	.316	.301	.288	.275	.263	.252	.241	.231	.222	.213	.204	.196	.188	.180	.173	60	2.750
70						.386	.368	.351	.336	.321	.307	.294	.282	.270	.259	.248	.238	.228	.219	.210	.201	70	3.208
80							.421	.401	.383	.367	.351	.336	.322	.308	.296	.284	.272	.261	.250	.240	.230	80	3.667
90								.452	.431	.412	.395	.378	.362	.347	.333	.319	.306	.294	.282	.270	.259	90	4.125
100									.479	.458	.439	.420	.402	.386	.370	.355	.340	.326	.313	.300	.288	100	4.583
110										.504	.482	.462	.443	.424	.407	.390	.374	.359	.344	.330	.317	110	5.042
120											.526	.504	.483	.463	.444	.425	.408	.391	.375	.360	.345	120	5.500
130												.546	.523	.501	.481	.461	.442	.424	.407	.390	.374	130	5.958
140													.563	.540	.518	.496	.476	.457	.438	.420	.403	140	6.417
150														.578	.555	.532	.510	.489	.469	.450	.432	150	6.875
160															.592	.567	.544	.522	.501	.480	.460	160	7.333
170																.603	.578	.555	.532	.510	.489	170	7.792
180																	.612	.587	.563	.540	.518	180	8.250
190																		.620	.594	.570	.547	190	8.708
200																			.626	.600	.576	200	9.167
210																				.630	.604	210	9.625
220																					.633	220	10.08
%	15.88	14.93	14.09	13.34	12.66	12.05	11.48	10.95	10.46	10.00	9.569	9.163	8.778	8.413	8.066	7.736	7.420	7.117	6.827	6.548	6.280	Royalty Rate	

Example: Lessee uses 100,000 gallons of fluid during one month @ an input temperature of 200°F and a discharge temperature of 100°F. The monthly production royalty due is $.326/1,000 gal., or $32.60.

* T = °Farenheit extracted by geothermal energy conversion process

** Base price - $5.50 per million Btu

4.2.7 Lease Terms, Adjustments, and Renewals

Geothermal energy is unique because it must be used on site, whether it be for electrical generation or direct utilization, and it often involves substantial capital outlays requiring amortization periods of 20-30 years for utilization facilities, pipe lines, and/or electrical transmission lines. Because of these factors, the effective lease life, adjustments of lease provisions during the life of the lease, and lease renewals are of great importance to developers. Equally important, from the government's side, is the prevention of land speculation on the part of the lessor, the ability to make adjustments in lease provisions to ensure compliance with state and federal environmental regulations, and assurances that a reasonable portion of the revenue generated from public lands is returned to the public treasury.

The use of exploration or prospecting permits which require work commitments, and which are granted for periods of 1-3 years, is an excellent way to prevent speculation. But it may discourage exploration if the permits are not convertible to leases, or if such permits do not provide the holder of the permit with a preference to a lease if and when leases are offered.

Noncompetitive and competitive leases are normally issued for periods of 10 to 20 years (see Table 4.3) (Sacarto, 1976). The longer a primary lease term, the more important it is that the lease carry reasonable diligence requirements to minimize having public lands locked up by land speculators. It is also extremely important that the primary lease term be of sufficient length to ensure that the developer has a reasonable opportunity to evaluate the leased area.

Most leases carry clauses which ensure an extension of the primary lease term if the developer is actively engaged in exploration and/or drilling, and all state and federal leases provide for an extension of the primary term once production of geothermal resources in commercial quantities begins. Such an extension is dependent upon continuous commercial production and is usually limited to 40-50 years (see Table 4.3), although Montana has not set a limit upon such an extension as long as geothermal resources are produced or are capable of being produced (Perlmutter, 1978). In the event

that leases are renewable beyond the end of the primary term they should provide for a preference to the lease holder.

One very important consideration which has surfaced since the enactment of most state and federal leasing statutes is a need to provide an extension of the primary lease term where, by no fault of the developer, commercial production cannot begin immediately, although resources capable of being developed have been discovered. A power surplus in the Pacific Northwest is forecasted to continue for the next 20 years, and the resulting low avoidance costs make it extremely difficult, if not impossible, to negotiate a power purchase agreement with the Bonneville Power Administration or with a utility in the BPA service area so that commercial production can begin. In addition, the lack of tie line capacity to California and the Southwest is preventing the sale of power to these areas where sale to an expanding market and high avoided cost could make geothermal energy development economically attractive.

Legislation considered by the 98th Congress (Senate Bills S 558 and S 883) would have allowed for an extension of the primary lease terms where commercial production cannot begin, and Section 7 of S 558 reads as follows:

> ...However, in the event construction of the (utilization) facility or facilities has not been possible due to administrative delays beyond the control of the lessee or due to the demonstrated marginal economics of such a (utilization) facility or facilities, and substantial investment in development of the lease has been made, the Secretary (of the Interior) will consider an additional extension of the extended primary lease term of up to 10 years: Provided, that the lessee be required to submit annual reports detailing bona fide efforts to resolve the administrative delays or to bring the (utilization) facility or facilities into economic production (United States Senate, 1983).

The 10 year extension proposed by S 558 and S 883 may, however, be inadequate in the Northwest due to the expected duration of the present power surplus. Because of the critical nature of this issue to the eventual development of geothermal resources in the Northwest and to the Pacific

Northwest Power Planning Council's (NWPPC) position on optioning, the states, BPA and the NWPPC should fully support legislation which would provide for an adequate extension of the primary lease term. Legislation addressing this issue is presently under consideration by the U.S. Senate Energy and Natural Resources Staff, as well as the staff of Senator Hecht of Nevada (Freihofer, 1984), and is expected to be introduced early in the 99th Congress.

Readjustment of terms during the period of the lease is another important issue, and consideration should be given to the effect that periodic renegotiations may have a deterring investment.

The Federal Geothermal Steam Act of 1970 provides for a readjustment of lease terms and conditions at not less than 10 year intervals after the date geothermal steam is produced. However, readjustment of rentals and royalties is restricted to not less than 20 year intervals beginning 35 years after the date geothermal steam is produced (United States, 1970).

The states of Idaho, Montana, Oregon, and Washington all provide for the readjustment of lease terms including rentals and royalties (see Table 4.3). For example, Montana requires a readjustment at 10 year intervals beginning 20 years after the lease date. The readjustment interval chosen by the states is often much shorter than that of federal leases and any adverse effect which this may have upon geothermal development should be given full consideration.

Frequent readjustments in rentals and royalties deter investments in geothermal development, and appear to be unnecessary because if royalties are based upon the price for which the energy is sold, revenues will increase at a rate proportional to the rate at which the value of the energy is inflating. The pricing formula for direct use resources being considered by the state of Washington (see Table 4.4) would, however, require frequent adjustments in the base price upon which the royalties are calculated.

Frequent adjustments in terms other than rentals and royalties have also drawn criticism, and have resulted in a reluctance on the part of utilities to utilize geothermal resources for power plant operation (United States

Department of Energy, 1979). However, as a result of the Report of the Interagency Geothermal Coordinating Council on Geothermal Streamlining Recommendations, legislation was introduced into the 96th, 97th, and 98th Congresses which would modify the readjustment provisions of the Geothermal Steam Act of 1970. Senate Bills S 558 and S 883, both considered by the 98th Congress, contained language which would have revised the adjustment period clause. Section 8 of S 558 reads as follows. "The Secretary (of the Interior) may adjust the terms and conditions,...,of any geothermal lease issued under this Act at not less than 20 year intervals beginning 20 years after the date production is commenced, as determined by the Secretary..." This would make for a 20 year readjustment period as opposed to the present 10 year period (United States Senate, 1983) and would help ensure utility participation in geothermal development.

4.2.8 Diligence Requirements

One of the most controversial provisions of leasing statutes is the requirement for diligent exploration. Diligent exploration can be encouraged through the use of escalating rentals (discussed in the section on rentals and royalties) or diligent operation can be mandated by requiring that specified sums of money be expended on exploration, or that certain activities, such as deep drilling, begin after a specified number of years. The requirements are necessary to ensure that lands are not held for speculation. Diligence requirements, however, should not be structured to force industry to expend large sums of money inappropriately. For example, drilling should not be required before the use of other less expensive exploration steps have been completed. The problems which diligent exploration requirements present to industry are compounded during a power surplus such as we are currently experiencing in the Pacific Northwest. Industry is forced to expend large sums of money in order to maintain a lease, while knowing full well that such expenditures may not be recovered during the forseeable future or that the primary lease term may expire before a power purchase agreement can be obtained. Lease holders are thus in a position that requires them to expend large sums of money with little guarantee of a reasonable return on investment, or drop the lease.

Diligence requirements, like provisions for the extension of lease terms, should provide for **exemption** or **extension** if justifiable by the lessee.

Senate Bills 558 and 883 which were considered by the 98th Congress both contain provisions for modifying the diligence requirements of the Geothermal Steam Act of 1970. The need for such provisions in future legislation should, however, be carefully evaluated in terms of their effect upon industry in a period of forecasted energy surplus, and by the fact that the Department of the Interior recently has adopted new rules which increase rentals or required expenditures on exploration beyond the fifth year of the primary lease term.

4.2.9 Summary

The preceding review of legal and institutional aspects of leasing is not a comprehensive treatise on the subject, but rather an attempt to highlight those issues which have the greatest impact on geothermal resource development in the BPA service area. Because leasing affects mainly high temperature development for electrical generation, a majority of these problems affect only the development of such resources. Geothermal resources utilized directly for industrial processes, space heating, and in agriculture and aquaculture applications seldom will be subject to state and federal leasing laws, but instead will be affected more directly by local permitting and land use ordinances, and the availability of water rights.

Gaining access to lands through leasing and the provisions of the lease are only two of many areas where legal and institutional requirements can have a profound influence upon a developer's ability to successfully complete a geothermal project to produce or offset electricity. Other subjects which must be evaluated include groundwater law, environmental reviews, exploration and development permits, facility siting requirements, and utility regulations. These subjects are examined in the following sections.

4.3 Groundwater Law

Groundwater is the principal geothermal medium of geothermal resources (except hot dry rock systems) by which the heat energy of the earth is conveyed to the surface. Most states have recognized the importance of groundwater in their definitions or characterizations of geothermal resources. In some states, such as Montana, geothermal resources have been declared to be a groundwater resource (Sacarto, 1976). In the other BPA regional states, Idaho, Oregon, and Washington, underground waters are divided into high and low temperature

regimes for purposes of regulation (see section on Resource Definitions). High temperature waters are considered geothermal resources and the low temperature waters are considered groundwater. In Oregon, the dividing line between high and low temperatures is 120°C (250°F) (Justus, et al., 1980). By making such a distinction based on temperature, the lower temperature resources are subject to groundwater law and regulation and not geothermal leasing law and regulation.

In Idaho, although geothermal is characterized as *sui generis*, an application for groundwater appropriation must be made if a geothermal well will yield water that can be used for beneficial purposes.* In addition, any consumptive use of geothermal water requires appropriation. Only in those cases where a geothermal well yields water that is used as a "mineral source, an energy source, or as a material medium," and does not involve consumptive use, is an appropriation of public water not required (McClain, 1979).

Although Idaho has attempted to minimize conflicts between geothermal and groundwater usage by differentiating between waters which have a beneficial use (groundwater that must be appropriated) and those which cannot be used for purposes other than for their energy or mineral content (and require a geothermal permit), it is advisable to obtain both a geothermal and water permit to protect and secure the developer's interests.

In Washington, as long as the resource is used solely for electrical generation, a water right is not required. However, if the resource is cascaded for other uses, a water right must also be obtained. Resources incapable of commercial electricity production are considered groundwater resources in Washington, and are regulated as such.

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*Beneficial use is defined by Idaho law as follows: "Beneficial use is a use of water that is reasonable and necessary to the user and is consistent with the interests of the public in the best utilization of water supplies. Beneficial uses include but are not limited to domestic purposes, agriculture, municipal and industrial supply, stock water, and fish propagation." (Idaho Department of Water Resources, 1980.)

Because historical uses of groundwater included domestic, agricultural, and industrial purposes, but not geothermal, conflicts between existing uses and the needs of the geothermal energy industry have become a serious consideration and one that can serve to severely limit geothermal development, especially in critical groundwater areas.

Montana has attempted to minimize conflicts through its claim that geothermal resources are water and must be regulated accordingly. A permit for appropriation is required for any use of water over 0.38 m^3 (100 gallons) per minute, and must be issued when the following criteria are met: (Montana Water Use Act 85-2-101 et. seg. M.C.A.) (Perlmutter and Birkby, 1980)

1. unappropriated water in the supply source is available, in the amounts and at the time of year required by the applicant;

2. the rights of prior appropriation will not be affected adversely;

3. the proposed means of diversion or construction are adequate;

4. the proposed use of the water is a "beneficial use;"

5. the proposed use will not interfere unreasonably with other planned uses or developments for which a permit has been issued or for which water has been reserved.

(Montana considers heat extraction a beneficial use.)

In Oregon, this issue is addressed in Chapter 522.255 of the Oregon Revised Statute. The Statute reads as follows: (Oregon, 1983)

> Resolution of conflicts between geothermal and water uses. If interference between an existing geothermal well permitted under this chapter and/or existing water appropriation permitted under ORS Chapter 537 is found to exist by either the State Geologist or the Water Resources Director, the State Geologist and the Water Resources Director shall work cooperatively to resolve the conflict and develop a cooperative management program for the area. In determining what action should be taken, they shall consider the following goals:

1. Achieving the most beneficial use of the water and heat resources;

2. Allowing all existing users of the resource to continue to use those resources to the greatest extent possible; and

3. Ensuring that the public interest in efficient use of water and heat resources is protected.

However, despite all attempts to minimize conflicts resulting from competing use, and to ensure that geothermal resources can be developed, conflicts have arisen and often with devastating results. Perhaps the best example of conflict between competing uses of geothermal energy can be found in the experience of Klamath Falls, Oregon.

The city of Klamath Falls, Oregon, began evaluating the feasibility of constructing a downtown geothermal district heating system in 1977, and by late that year received notification from the U.S. Department of Energy that it would receive demonstration funds under a federal USDOE grant program. The city began by drilling two successful production wells, and after confirming the resource, construction of the system began in earnest. Klamath Falls, however, is an area where geothermal energy has been utilized by a few hundred homeowners and commercial establishments since the early 1900's. These users began to worry that the city system would, in spite of injection of the fluids into the reservoir, adversely affect their own geothermal energy supply. Because of these fears, a citizen's initiative, organized by the Citizens for Responsible Geothermal Development (CRGD) was successful in gathering over 1,500 signatures within the city. When the initiative measure was voted on in 1981, the future of the city's geothermal system received a serious setback. The initiative, which passed 788 to 567, prohibited "persons, cooperatives, organizations, municipal corporations, or any political subdivision of the state of Oregon from withdrawing geothermal water 'from a well unless it is returned' undiminished in volume to the **same well.**" (Emphasis added) The effective result of the initiative was to prevent the city from using either of the two wells (even though the entire system was completed and ready to begin operation in 1982), and forced the city to consider alternative heat sources (United States

Conference of Mayors, 1982).* The future of the system is still in limbo. However, long term reservoir tests were completed in 1983 which indicated that existing wells would be only marginally affected by the operation of the city's district heating system, and the initiative was amended by the City Council in early April 1984, allowing for testing of the system (Allen, 1984). On November 9, 1984, the city began a full operation test of the system with the intent of operating throughout the 1984-85 heating season. At the end of that test, a determination will be made regarding future system operation. What future legal action, if any, that the CRGD or other groups will take is at this time unclear.

In Pagosa Springs, Colorado, approximately 30 well owners and the owner of a hot springs resort--fearful that the construction of a proposed district heating system would adversely effect the availability of geothermal resources for existing use--succeeded in delaying the start of the city's geothermal district heating system by more than two years. And, although the city expects to be able to begin operation of the system in late 1984 or early 1985, it may be some time before the courts settle the water right issues which have been at the heart of the conflict (Rogers, 1984).

The Klamath Falls example, as well as the problems experienced by the city of Pagosa Springs, Colorado, only serve to emphasize the importance of groundwater to direct use geothermal development (Allen, 1984a). The Oregon court decisions are extremely important to the development of local geothermal district heating systems as it provides a means by which local jurisdictions at least in Oregon can control the development of geothermal resources for such purposes. A determination should be made whether or not such local control can be exercised in Idaho, Montana, and Washington.

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* The state of Oregon challenged the initiative in Circuit Court, lost, and appealed the decision. The Appellate Court upheld the lower court ruling, as did the Oregon Supreme Court (Deitah, 1984). The essence of the ruling is that local governments have the authority to adopt regulations consistent with the policy of the Ground Water Act as outlined in ORS 537.525 (Lienau, 1984).

The conflict between geothermal development and historical uses of groundwater has also been a major concern in the Raft River geothermal field in southern Idaho. The area has been declared a critical groundwater area and further exploitation of groundwater resources in the area is prohibited. The unavailability of groundwater for use in the cooling towers has required that geothermal fluids be used for cooling, resulting in technical problems and increased cost of operation. In order to obtain an appropriation for the needed cooling water an existing water right would have to be purchased, resulting in diminished agricultural production in the area.

4.4 Environmental Analysis

Providing adequate protection for the environment is undeniably a major responsibility of government which balances the relative priorities of developers' rights under the Geothermal Steam Act of 1970 against the rights of the general public embodied in NEPA, resource management laws, and management plans for the lands involved. How that protection is structured and administered by responsible state and federal agencies will have a profound impact upon a developer's ability to successfully complete a geothermal project in an economical and timely fashion.

The federal government and the four regional states have adopted environmental statutes which require that all major activities proposed be subjected to a review of possible environmental impacts.

The Geothermal Steam Act of 1970 was the first major legislation to be enacted after the passage of the National Environmental Protection Act, and managers of federal lands, as well as developers, were presented with an uncharted course to follow. The result has often been confusion, and serious delays, in the leasing of federal lands and in the processing of permit applications.

The worst delays have occurred in the processing of federal noncompetitive lease applications and the offering of federal KGRA lands for lease sale. The primary cause of these delays has been the view of surface management agencies that pre-lease environmental analyses must consider the environmental impacts of all exploration and development activities--in other words, a pre-lease environmental analysis was based upon a worst case development scenario. The situation was aggravated in the Northwest where the United States Forest

Service (USFS) was assigned surface management responsibilities and the Bureau of Land Management (BLM) subsurface management responsibility in the same area. The General Accounting Office in 1980 found that "The Forest Service...has made considerably less progress in leasing its lands (than the BLM)...Unless geothermal leasing is given higher priority within the Forest Service, we believe it could be a matter of concern for future geothermal development." The situation has improved dramatically since the late 1970s, and at present the USFS claims that most lease applications can be processed within one year. There are, however, lease applications in extremely sensitive areas or wilderness study areas which date back to 1974 which have not been processed.

In 1983, the U.S. Forest Service began experimenting with the use of Conditional Right Stipulations (CRS). The CRS was to be used in order to get away from the need to employ the worst case scenario in the preparation of environmental analyses and to speed leasing. Under CRS, pre-lease environmental analyses are limited to determining areas which are totally unacceptable to development activities. Detailed environmental reviews are undertaken only in response to specifically proposed activities in a lease area. In this way, the environmental review is restricted to the evaluation of each proposed activity in relationship to the exact area where the activity will be undertaken. For example, since very little environmental degradation is likely to occur from surface geological exploration or geophysical and geochemical surveys, an extensive environmental review should not be required. However, as the drilling of deep exploratory wells is planned and sited, an environmental analysis of much greater detail would be required, but such an analysis would be restricted to the immediate area where the drilling was to take place. Finally, if a commercial geothermal resource is encountered and a permit application for facility construction is filed a detailed environmental analysis can be completed which is based upon the qualities of the resource, knowledge of any environmentally hazardous substances present in the fluids, the proposed conversion and disposal technologies, and the proposed site for facility construction.

Although the use of CRS appears to have been quite successful with leases being issued after only minimal delays, its use was discontinued in April 1984. The Contingent Right Stipulation Test was, according to the U.S. Forest Service, terminated because "the degree of acceptance has not been sufficient to continue." (Department of Agriculture, 1984.) This could signal a return to the

delays which have plagued the industry since 1974 unless the surface management agencies are able and willing to base pre-lease environmental reviews on completed forest management or land use plans, or a greater priority is given to the processing of lease and permit applications.

The final passage of Wilderness Bills affecting lands in Idaho, Oregon, and Washington in 1984 has served to simplify the preparation of environmental analyses for the leasing of Forest Service lands.

Environmental analyses on state lands have not resulted in serious delays in the issuing of leases or subsequent permits and licenses, and should not be considered a major constraint to exploration and/or development.

Specific environmental considerations such as water and air pollutants, land subsidence, induced seismisity, noise, land and water use, and economic, social, and cultural impacts will be treated in a subsequent section of the report.

4.5 Exploration, Drilling, and Production Permits

Permits for exploration, drilling, and production on available federal lands are issued by the Department of the Interior, Bureau of Land Management (BLM), pursuant to the Geothermal Resource Operational Orders (United States Geological Survey, 1979).

Permits to conduct surface exploration and to drill temperature gradient holes to a depth of 150 m (500 feet) are issued to an applicant after a finding of no significant environmental impact by the BLM. Applications for such permits, entitled a "Notice of Intent and Permit to Conduct Exploration Operations," can be filed by developers on all federally managed lands, including lands in KGRAs, and including lands which are under lease application by another developer. Federal permits also may be issued to lease holders, as well as to non-lease holders, which allow for the drilling of exploration holes to a depth of 900 m (3,000 feet) upon the approval of a Plan of Operation filed by the applicant.

All post-lease exploration activities on federal lands are carried out under a Plan of Operation approved by the BLM and with the concurrence of the surface management agency. Permit applications for all such post-lease exploration activities require the completion of an environmental review by the responsible surface management agency before permit issuance (Fujimoto, 1984).

All pre- and post-lease exploration activities on state and private lands are under the jurisdiction of the State Geologist or the Director of the Department of Water Resources.

Resource production on all federal lands is regulated through a Plan of Production approved by BLM. Before such a Plan of Production can be approved, the applicant must gather environmental baseline data describing the existing environment for one year. No Plan of Production can be approved by the BLM until after completion of an environmental review, and such approval must have the concurrence of the surface management agency if other than the BLM. A finding of significant environmental impact during the review process will require the preparation of an Environmental Impact Statement (EIS) pursuant to the National Environmental Protection Act before the plan may be approved. The EIS will be prepared by the Bureau of Land Management, and must be approved by all other responsible land management agencies.

BLM, as the lead agency for facility siting on federal lands, would serve to coordinate the processing of all applications to construct energy conversion facilities on federal lands. The construction of related transmission lines is regulated on federal lands by the responsible surface management agency. The construction of geothermal energy conversion facilities is regulated under the provisions of the Geothermal Resource Operational Orders, and all permits to construct conversion facilities and/or transmission lines must have the concurrence of the appropriate land management agency. On state and private lands this responsibility often resides with an Energy Facility Siting Council or Agency. State energy facility siting authority over state lands may extend to the siting of energy facilities on federal lands, as has been claimed by the Oregon EFSC. However, whenever the state exercises authority over the construction of energy conversion or transmission facilities on federal lands, the state may do so only after necessary federal permits have been approved. Oregon's Energy Facility Siting Act is one of the most comprehensive and will be examined here in detail.

The Oregon Energy Facility Siting Council (EFSC), established under provisions of the state Energy Facility Siting Act, claims jurisdiction over certain energy facilities on all lands, private, state, or federally owned. Site certifications are required by the EFSC for any geothermal power plant with a nominal electrical

generating capacity of more than 25 megawatts; pipelines transporting geothermal fluids which are six inches or greater in diameter and five miles or longer in length; and high voltage transmission lines of more than ten miles in length with a capacity in excess of 230,000 volts (Justus, et al., 1980).*

The Oregon EFSC has adopted general standards which apply to all energy facilities and require the following mandatory findings: 1) need for the proposed facility based on energy demand and economic prudence; 2) protection of public health and safety; 3) environmental protection; 4) beneficial use of wastes and byproducts; 5) conformance with statewide planning goals and comprehensive land-use plans; 6) protection of historical and archaeological sites; 7) no infringement on existing water rights; 8) necessary expertise to operate, construct, and retire the facility; 9) reasonable assurance of obtaining the necessary funds, and 10) identification of foreseeable socioeconomic impacts in the vicinity of the proposed facility (OAR 345-74-025) (Justus, et al., 1980).

The Oregon EFSC also has the power to conduct investigations into all aspects of site selection, to designate areas within the state as suitable or unsuitable for geothermal power plants, and to establish standards and promulgate rules which must be satisfied in order to obtain a site certification.

The power of the EFSC to designate areas unsuitable for geothermal power plants has resulted in a decision by the Council in the mid 1970s that, because of high recreational use and lack of roads, geothermal power plants greater than 25 MWe could not be constructed on portions of Newberry Volcano, including the caldera. This area has since been determined to be one of the highest potential geothermal areas in the Northwest. The ruling tends to deter exploration in this high potential area, and long has been argued to be premature since the decision was reached without sufficient information concerning the nature and occurrence of the resource or the energy conversion technology which would be employed. In addition, the roadless area is now scheduled for logging and the United States Forest Service has allowed leasing of much of the land.

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* The United States Department of the Interior Bureau of Land Management does not, however, recognize EFSC authority over federal lands, but will make every attempt to coordinate and cooperate with EFSC on the siting of facilities within the state of Oregon (Mohorich, 1985).

A very important element of state energy facility siting statutes, and a critical role of the implementing authority, is to provide for the coordination of permits and license applications through all state and local agencies affected by such an application, and ensure that the coordination with other agencies makes siting of all energy facilities a one step process for applicants. This procedure saves both time and money, and ensures that all applications are handled and evaluated in a consistent manner. Once a siting certificate for a transmission or energy conversion facility is granted, all state and local agency permits and licenses must automatically be granted. Each permitting agency, however, retains the authority to enforce all requirements of the permit or license issued. Examples of some of the permits required include: conditional land use permits, construction permits, drilling permits, a permit for the disposal of liquid wastes, and permits for air emissions.

Unlike Oregon, Montana and Washington have given the energy facility siting authority limited powers over only state and private lands. For example, in Washington, the Energy Facility Siting Evaluation Council (EFSEC) maintains siting jurisdiction over all lands, private and state owned, but only in the case where on-site improvements to an existing facility exceed $250,000, or a proposed generating plant has a capacity of 250 MWe or more (Bloomquist, et al., 1980). Thus, geothermal development would not be expected to fall under the jurisdiction of the EFSEC, and would instead be regulated by the Departments of Natural Resources and Ecology. The exemption of most geothermal developments in Washington from EFSEC regulations may, as some developers contend, simplify the siting process, but, on the other hand, the ability of the EFSEC to coordinate the processing of an application through all state and local agencies could result in substantial savings in both time and money, and as such, would help to shorten the lead time from exploration to plant construction and power on-line.

Authority for the construction of energy conversion facilities in Montana is handled by the Board of Natural Resources and Conservation under the Major Facility Siting Act.

Idaho has no facility siting agency, but the Public Utilities Commission (PUC) plays a strong role in this regard.

4.6 Utility Easements

The culmination of any successful geothermal exploration and development project is to deliver the energy to the user. However, the ability to deliver energy to market, either in the form of hot water or electricity is dependent upon both the economics of constructing pipelines or power lines, and also upon the developer's ability to obtain easements across federal, state, local, and/or private lands for the construction of such pipelines or electric transmission lines. The lack of existing power lines or lines with available capacity has been singled out as one of the major impediments to geothermal development in Nevada and has also been identified as one of the economic barriers to development in the BPA service area (McClain, 1984).

The ability to obtain easements to cross both public and private lands is simplified if such easements are for "public use." The public use requirement is satisfied by most definitions of a "public utility," and, therefore, a closer examination of utility law is needed in order to determine the utility status of both geothermal electrical and geothermal direct use projects.

Public utilities are entities (individuals, corporations, associations, etc.) that supply services considered indispensable to the public, and are thus "affected with a public interest" (Nimmons, et al., 1979). Although "services" are defined differently from state to state, suppliers of heat, water, electricity, and natural gas are commonly considered to be subject to public utility statutes.

> In Idaho the term "public utility" includes: ... every common carrier, pipeline corporation, gas corporation, electrical corporation, telephone corporation, telegraph corporation, motor corporation, and wharfinger, as those terms are defined in this chapter and each thereof is hereby declared to be a public utility and to be subject to the jurisdiction, control, and regulation of the commissions and to the provisions of the act: provided that the term "public utility" as used in the act shall cover cases both where the service is performed and the commodity delivered directly to the public or some portion thereof, and where the service is performed on the commodity delivered to any corporation or corporations or any person or persons, who in

turn, either directly or indirectly or mediately or immediately, perform the services or delivers such commodity to or for the public or some portion thereof (C.61-104).

Montana's Public Utilities Regulation Law (Title 70, Chapter 1, R.C.M., 1947) defines a public utility as:

> ...every corporation, both public and private, company, individual, association of individuals..., that now or hereafter may own, operate, or control any plant or equipment, within the state, for the production, delivery, or furnishing for as to other persons, firms, associations, or corporations, private or municipal, heat,...power in any form or by any agency, water for business, manufacturing, household use...whether within the limits of municipalities, towns, or villages, or elsewhere...(Perlmutter, 1978).

Oregon Revised Statutes 757.005 defines public utility as follows:

> Any corporation, company, individual, association of individuals, or its lessees, trustees or receivers, that owns, operates, manages or controls all or a part of any plant or equipment in this state for the conveyance of telephone messages, with or without wires, for the transportation of persons or property by street railroads or other street transportation as common carriers, or for the production, transmission, delivery or furnishing of heat, light, water or power, directly or indirectly to or for the public, whether or not such plant or equipment or part thereof is wholly within any town or city.

Washington Revised Code § 80.04.010 defines public service companies to include gas, electric, and water companies, among others.

Thus, under most utility statutes, both electrical generating and district-sized direct use projects would be considered to be public utilities entitled to apply for easements across state and federal lands for the construction of needed pipelines and electric transmission lines. This does not imply in anyway that geothermal developers should desire to be regulated as public utilities. However, utility law clearly indicates that geothermal developers would be eligible for utility status should it be necessary to gain an easement.

Applications for such easements are made through the appropriate office of the responsible land management agency. Applications require the preparation of environmental reviews and, if there is a finding of significant environmental impact, an environmental impact statement will be required and prepared under provisions of the appropriate state or national environmental protection act. If the easement is granted, the applicant will be required to pay annually the fair market value of the interest in the land being acquired.

Easements are also required to cross city or county properties, and may be granted as a public use by the city or town councils, boards, or county commissioners.

If pipelines, transmission lines, or other facilities for developing or using a geothermal resource must cross privately owned lands, the geothermal developer must negotiate with the landowner(s) for the necessary easements, and, if that fails, seek to acquire such an easement through the right of "eminent domain." Eminent domain is the right of the state or other entities operating in the public interest to take private property for "public use" (Perlmutter and Birkby, 1980).

In order to use eminent domain, the developer must file a complaint in court describing the proposed public use, the source of the right to such use, the property interest sought, and the present ownership(s). The court must determine whether the proposed use is an authorized public use, and establish the amount of property to be taken. The court may also determine the appropriate compensation to be paid by the petitioner.

It is clear that both district-sized direct application and electrical generating geothermal projects may be included under utility law, and that such projects built for "public use" are assured that utility easements can be secured.

However, the benefits obtained in acquiring easements through utility status may be offset by other aspects of utility law and developers may choose to fight utility status because of the adverse effects of regulation. A complete discussion of the effects of utility regulations is unfortunately beyond the scope of this study.

4.7 District Heating Authorization and Regulation

4.7.1 Introduction

The primary focus of this report in regard to the direct utilization of geothermal resources has been on the use of such resources for district heating. It is thus extremely important to give consideration to what entities logistically would be involved in the development of district heating systems, what the legal status of district heating systems is, and how development of such systems can be expected to be regulated.

Geothermal district heating development logically could be considered to be actively pursued and developed by the following participants:

1. Energy companies,
2. Industrial and commercial users,
3. Utilities, and
4. Municipalities.

Energy companies, including major oil and gas exploration companies, have shown a great deal of interest in high-temperature geothermal resources generating electricity. However, these same companies have expressed very little interest in exploring or developing low- to moderate-temperature geothermal resources for district heating. This can be attributed to a relatively low rate of return on such projects in relationship to the high cost and high risk associated with exploration and drilling.

Industrial and commercial users willingly would use geothermal heat if it were delivered to them by a district heating supplier much as conventional energy supplies are, but are generally unwilling to take the risks of exploring for or developing geothermal resources themselves because of their lack of expertise in the development of energy projects (King, et al., 1980).

Investor-owned utility companies are generally unwilling to engage in high risk geothermal exploration and development activities because utility commissions are reluctant or refuse to allow the inclusion of "dry holes" in the rate base or the allowable rate of return would be too low because of regulation.

Publicly-owned utilities are often statutorily prevented from engaging in high risk geothermal ventures or are unable to assume the risks of geothermal exploration and development.

Finally, municipalities have shown much reluctance to engage in high risk ventures because of a lack of available funds for such projects, a lack of in-house expertise to successfully undertake such a project, and because they lack clear legislative authority to become involved in district heating.

Although some entities have been historically unwilling or unable to become involved in the development of district heating systems, there are small, independent geothermal resource companies who are involved in the exploration for or development of geothermal resources. These projects usually involve the development of mini district systems such as industrial and office parks, shopping centers, hotels, condominiums or townhouse complexes, and single-family residential tracts. And although these companies also have expressed an interest in installing city-wide district heating systems which use geothermal resources, the public utility implication of such projects and the risks of becoming a regulated public utility have increasingly been voiced as profound disincentive to the development of these types of projects by small, independent geothermal developers.

In spite of these problems, the development of geothermal district heating systems has begun to accelerate, and with the aid of federal funding, systems are now in operation in Boise, Idaho; Klamath Falls, Oregon; and Ephrata, Washington. Others are being considered for Boulder, Montana; Stanley, Idaho; Vale and Lakeview, Oregon; and North Bonneville, Yakima, Grandview, and Sunnyside, Washington.

To fully understand the increased interest in geothermal district heating we must examine the legal changes which have occurred in the four states to make such development possible and attractive to public as well as private sector developers, and to examine whether or not a framework conducive to the development of district heating has been adequately established.

4.7.2 Public Sector Participation

One of the biggest impediments to public sector participation in district heating was removed when, over the past several years, the states of Idaho, Montana, Oregon, and Washington passed legislation to guarantee the rights of local governments to engage in district heating and clarified their right to finance, construct, own, and operate district heating systems within their jurisdictions.

Such authorization served as an important step toward furthering development of district heating systems by the public sector. However, another major impediment to local government development of geothermal district heating systems--the inability to engage in high risk ventures because of the lack of funds to engage in exploration and resource development continues to delay or impede public sector participation.

One possible way in which such funding could be made available has recently been adopted by the state of Minnesota. The Minnesota legislature authorized the sale of $100,000,000 worth of bonds which will be used for assisting communities engage in the study, design, and construction of district heating systems. And, although none of the Pacific Northwest states have adopted a similar funding mechanism, the Washington State Energy Office is looking into the need and desirability of requesting that legislation similar to that passed in Minnesota be introduced.

Another mechanism for municipalities to obtain necessary funding may be provided through private sector participation in the design and construction of district heating systems. However, as mentioned earlier, the public utility implication of such projects and the risks of becoming a regulated public utility have discouraged such participation.

4.7.3 Private Sector Regulation

Because most conventional financing institutions are reluctant to fund high risk ventures, and because federal and state funding is, to a large extent, unavailable at present, most geothermal district heating projects will have to be financed largely by equity investors whose primary inducement will be return on investment. Investors must, therefore, have assurance that if economically exploitable resources are confirmed through high risk drilling

ventures that applications can be developed which yield a rate of return commensurate with the risk.

Presently, private developers cannot confidently predict whether the most likely geothermal applications actually will result in public utility status under current law and practice if the application requires resource distribution as would be the case with a district system.

Another major concern is the prospect that cost-based rate regulations probably will yield at most a 15 percent return on investment--far below the minimum 35-40 percent return generally considered necessary to attract investors to high-risk geothermal projects. Other consequences of traditional utility regulation include possible disallowance of the cost of unsuccessful wells, denial of the federal 15 percent business energy investment credit, and the imposition of administrative and financial burdens which may be disproportionate to the benefits which the developer and its investors might anticipate from relatively small-scale heating operations dictated by resource limitations.

Recent legislative initiatives directed toward removing the disincentives which traditional public utility regulations impose may, however, provide a way through which the private sector can become actively involved in district heating.

The state of California legislated a total exemption from utility regulations for those engaging in geothermal district heating. The states of Nevada (Nevada Revised Statute 534A.010) and Washington (Engrossed Substitute House Bill 114, 1983) have adopted a much simplified operating permit system in place of traditional regulations. Under the permit system, geothermal sales are conditioned only on UTC issuance of a permit which:

1. specifies a geographic service area;
2. authorized non-exclusive services within that area, whether or not served by another utility; and
3. provides for UTC or PSC review and approval of basic system design, and of essential terms in the supplier's proposed form of customer contract, including length of term, a maximum rate or rate formula

(unrelated to cost of service), and a streamlined dispute resolution procedure.

Such a system eliminates the major barriers to development described earlier, while still affording geoheating customers basic protection against supplier abuses which could arise once customers have been induced to make the initial investment needed to utilize the resource.

The states of Idaho, Montana, and Oregon should seriously consider exempting district heating systems from traditional utility regulations, especially in light of a 1985 study released by the National Research Council in which utility regulation of district heating was singled out as one of the major disincentive to the widespread development of district heating (National Research Council, 1985).

4.8 Conclusion

The maze of federal, state, and local legal and institutional requirements can sorely test the endurance and patience of most developers of geothermal energy. Delays in obtaining leases as well as required licenses and permits have, at times, taken up to 10 years, and often have been cited as the primary reason for the lack of geothermal assessment and development in the states of Idaho, Montana, Oregon, and Washington.

The problems, however, have diminished over the years--federal and state legislatures and regulatory agencies have striven to establish a legal and institutional framework conducive to geothermal development. And, although many of the barriers identified are presently being addressed through state and/or federal legislation and changes in implementing rules and regulations, it is imperative that the states, BPA, and the responsible regulatory agencies work together to ensure that barriers to geothermal exploration and development are removed in as timely a manner as possible so that cost-effective geothermal energy will be available to the region when it is needed.

CHAPTER 5

Environmental Issues

5.0 A REVIEW OF THE ENVIRONMENTAL EFFECTS OF GEOTHERMAL DEVELOPMENT AND SUGGESTIONS FOR MITIGATION

5.1 Introduction

Although geothermal resources often are considered a relatively clean energy source which is environmentally benign, adverse environmental effects have occurred in various parts of the world due to geothermal exploration and development. The degree to which geothermal development affects the environment is, in most cases, proportional to the scale of such development. For example, the environmental impacts associated with geothermal direct use projects often are minimal compared to those associated with electrical generation projects. In most cases, direct use projects are designed as a closed loop, where low- or moderate-temperature fluids are withdrawn, passed through a heat exchanger or heat pump, and injected back into the producing aquifer without any exposure to the environment or discharge at the surface. In electrical generating projects, geothermal water is more often exposed to the atmosphere as resources are flashed to steam, or dry steam is brought to the surface to drive turbines. Exceptions, however, exist, e.g., binary generation allows for the use of a closed loop with little or no exposure of the geothermal fluids to the atmosphere or to surface water.

Because electrical generation projects present the greatest threat to the environment, this section will focus primarily on the effects which may be associated with such development, and methods for dealing with these effects. However, wherever applicable, environmental effects which can be the result of direct use projects will also be discussed.

The main environmental factors to considered during geothermal exploration and/or development, include: the release of airborne effluents; water pollution; earth subsidence; induced seismicity; noise; water supply; solid waste; land use; vegetation and wildlife; and economic, social, and cultural factors. Table 5.1 summarizes these effects for the major steps during exploration and development. Tables 5.3 and 5.4 compare a vapor dominated system at The Geysers in Northern California with a hydrothermal resource in the Imperial Valley of Southern California.

Although it is impossible to predict the type of system(s) which will be encountered in the Cascade or Basin and Range Provinces of the Pacific Northwest, these tables do give an indication of the major differences between vapor dominated and hot water systems.

5.2 Airborne Effluents

Although air quality impacts which could be expected to result from a single geothermal facility would usually be minimal on a national or even on a regional basis, local effects may be significant because of site-specific factors. The cumulative effects of emissions from several facilities in one geographic area may create significant air pollution problems. The complex geochemistry of geothermal resources is exemplified by variations in concentrations of noncondensible gases from field to field, as well as variations from wells tapping the same aquifer (U.S. DOE, 1980). For example, the fractional content of noncondensible gases varies from 0.4 percent by weight at The Geysers, California, to 30 percent at Monte Amiata, Italy. The major constituent of this fraction is typically carbon dioxide, with lesser amounts of ammonia, methane, hydrogen sulfide, mercury, radon, boron, and trace metals (Table 5.2). Noncondensible gases escape from the system by condenser gas ejection, cooling tower exhaust, power plant by-passing during shut down, and well venting (U.S. EPA, 1978).

Hydrogen sulfide (H_2S) usually is the most troublesome of the gases because of its objectionable odor even at low concentrations (Bowen, 1973). H_2S may also cause headaches, fatigue, irritability, insomnia, and gastrointestinal disturbances with limited exposure. In somewhat higher concentration, the gas acts as a nervous system stimulant, causing excitement and dizziness (Milby, 1962). Systemic H_2S poisoning can result in respiratory failure and asphyxia (Zerwas, 1979).

The greatest danger to personnel from H_2S occurs during well drilling operations. During drilling, pockets of H_2S may be encountered, and the pressure of the drilling "muds" may be insufficient to contain the gas.

TABLE 5.1

ENVIRONMENTAL MATRIX FOR GEOTHERMAL DEVELOPMENT

	EXPLORATION	PRODUCTION DRILLING & TESTING	PARALLEL FIELD DEVELOPMENT OPERATIONS	PLANT CONSTRUCTION	FULL-SCALE OPERATIONS
	o Mapping/field studies o Drilling pad construction o Test drilling (shallow and small diameter) o Temporary roads/traffic o Equipment opertion	o Well drilling and construction (production and reinjection) o Well stimulation o Accidental blowouts o Well testing/ venting, ponding/ reinjection	o Land clearing and roads/vehicular traffic o Gathering systems o Equipment activities o Service living quarters o Water, sewage, temporary electricity and other supporting services	o Structures and improvements o Vehicular traffic/ equipment o Activities o Special construction activities (e.g., blasting) o Electric transmission systems o Supporting services (e.g., water, electricity)	o Cooling towers o Venting (during short-term outages) o Well head bleeding o Reinjection o Recharge, stimulation, and redrilling o Corrosion and scale control o Gaseous, liquid, and solid wastes o Work force movement o Abandonment
ASPECTS OF THE ENVIRONMENT					
Air Quality	H	L/H	L	L	L/H
Water Resources	L	L/H	L/M	L	L/H
Wildlife & Vegetation	L	L/M	L/M	L/H	L/M
Geology & Soils	L	L/M	L/M	L/M	L
Noise	H	M/H	M	M	L/M
Social, Economic, & Cultural	L	L/M	L/H	L/H	L/H
Health & Safety	L	M	L	L	L/H
Land Use	L	L	L/H	L/H	L

H= High potential impacts; long-term and/or great intensity

M = Moderate potential impacts; major short-term and/or overshadowed effects

L = Low/negligible potential impacts; minor and/or short-term

(FERC, 1981)

TABLE 5.2 - MAJOR NONCONDENSABLE GASES FROM GEOTHERMAL WELLS

	Typical Emissions (g/MWh)	Significant Environmental Effects	Applicable Environmental Regulations	Control Likely
Carbon dioxide	80,000 - 100,000	None	None	No
Ammonia	400 - 2,000	None	Occupational standards only	No
Methane	300 - 3,000	None	None	No
Hydrogen sulfide	50 - 1,200	Odor; high concentrations are occupational hazard	State ambient standards and proposed emissions limits	Yes
Mercury	0.09 - 0.7	Toxic	Federal standards	Possibly
Radon	40,000 - 50,000	Radiation hazard	Federal standards	Possibly
Trace metals	--	Toxic	--	Unknown

(FERC, 1981)

Available mitigation measures include equipping the drilling rig with alarms that indicate when H_2S levels reach a hazardous level so that personnel may don emergency breathing equipment. Blowout preventers can be activated to control gas release from high pressure pockets. Cyclone mufflers can scrub some of the H_2S out of the steam. Injecting solutions of sodium hydroxide and hydrogen peroxide in the line in front of the muffler has been used to remove H_2S successfully (Zerwas, 1979).

H_2S released within the facility may occur in high enough concentrations to cause discomfort; however, no evidence exists that H_2S occurs in ambient concentrations at levels that could jeopardize public health or welfare.

Treatment technologies have been developed to control H_2S emissions from geothermal facilities, and several additional techniques are now under development (Helfritch, et al., 1983). Several processes which have been utilized for the removal of H_2S from power plant effluents or which are under development are as follows:

- The Cycloform Scrubber;
- The Coury Heat Exchanger Process;
- The EIC Corporation's copper sulfate ($CuSO_4$) process;
- The Stretford process;
- The Dow Oxygenator procedure;
- The iron catalyst method; and
- The electron beam induced H_2S removal system

  (FERC, 1981; Coury, et al., 1983; Helfritch, et al., 1983; Geothermal Power Company, 1981).

The best H_2S removal process selected varies from site to site, depending upon the composition of the geothermal resource (FERC, 1981). Because nearly all H_2S abatement methods will produce a sludge by-product, a cross-media environmental impact of concern results and suitable sanitary landfill disposal sites are required to dispose of the sludge.

Various emission limits for H_2S released from geothermal facilities have been proposed or are being considered. These limits would apply to all facilities, and range from 50g/MWh proposed by the state of California, to 400 g/MWh being considered by the EPA. Uncontrolled emissions from existing geothermal wells in the western United States range from 110 g/MWh to 1,200 g/MWh (White, 1978; Ermak, et al., 1979). Depending on the H_2S content of the well, control of as much as 96 percent of the H_2S could be required if the most stringent control measures are adopted.

Presently available evidence indicates that H_2S emissions from hydrothermal operations which employ mechanisms for H_2S removal will not cause serious vegetation damage (Thompson, et al., 1982; Gonzales, 1984). More research, however, is needed to confirm this with additional plant species, and to examine the synergistic action of H_2S with other pollutants such as O_3. In the atmosphere, H_2S is slowly oxidized to SO_2 and SO_4. The formulation of sulfate and other sulfur-containing particulates is therefore certain. However, the slow conversion rate of H_2S to other sulfur compounds indicates that this will probably not occur at the site, but could occur elsewhere because dispersion will have occurred while conversion is taking place.

Minor amounts of hydrogen sulfide also may be associated with geothermal fluids utilized in direct applications. Since these systems are, however, normally "closed," little if any H_2S is released to the atmosphere and the main concern is corrosion of piping and heat exchangers.

Boron has been found to be a cause of stress and serious damage to certain native trees and shrubs near geothermal power plants at The Geysers (Brownell, 1981). Some of these species are big leaf maple (*Acer macrophyllum*), madrone (*Arbutus menziesii*), Douglas fir (*Pseudotsuga menziesii*), yellow pine (*Pinus ponderosa*). scrub oak (*Quercus dumosa*), and sugar pine (*Pinus lambertiana*) are common to the Pacific Northwest (Malloch, et al., 1979).

Power plant cooling water at The Geysers is derived from condensed steam, and some boric acid from this condensate escapes from the cooling towers in drift droplets. Boric acid is also a major pollutant at Larderello, Italy, where boric acid extraction from geothermal fluids is a major industry. The boric acid problem at The Geysers could be mitigated by use of other sources of water for cooling. It may also be possible to remove boric acid through Cycloform Scrubber steam cleaning, and an H_2S removal system on the upstream side of the turbine (Geothermal Power Company, 1981).

It is unclear whether boron will present a serious environmental problem at other geothermal sites. Boron and the release of boric acid have not been traced to any adverse health effects.

Although ammonia (NH_3) may make up a substantial percentage of the noncondensate gas from geothermal wells (Table 5.2), the environmental effects of airborne release appear to be minor.

The emission of radon at The Geysers power plant has been studied in detail by Anspaugh (1978), who concluded that effects from radon emission are not discernable in the general environment of the power plant, or in downwind communities. However, recent concerns over the health risks which may accrue from radon exposure make adoption of stringent controls likely, and the development of control mechanisms probably will be required.

Arsenic is a frequent constituent of geothermal fluids (Weres, et al., 1977; Crecelius, et al., 1976). Although arsenic releases are quite small compared to H_2S, arsenic is an elemental poison and also is a carcinogen. The environmental effects of arsenic emissions from geothermal facilities have been minimal and no control mechanisms have been required (FERC,1981).

Although Mercury is almost always found in trace amounts in geothermal fluids, it appears to be a marginal contaminant (FERC, 1981). Mercury emission rates recently reported for The Geysers and Cerro Prieto, Mexico, indicate that airborne release rates are extremely small, only 90 micrograms per kilowatt-hour (Mg/kWh) at Cerro Prieto, and 30 to 70 Mg/kWh at The

Geysers. Ambient air at The Geysers has the same concentration of Mercury as that at background locations. Measurements of ambient air at Cerro Prieto showed somewhat higher background levels. On a per megawatt basis, emissions of Mercury from geothermal power plants are comparable to the release of Mercury from coal-fired power plants (Robertson, et al., 1975).

In addition to the more common and better understood noncondensible gas constituents mentioned above, more detailed source-term measurements at additional sites of hydrothermal use are needed to determine the levels of other trace elements which may be released. In particular, information on hydrogen flourides, mercaptans, and volatile hydrides is needed.

5.3 Water Pollution

Water pollution can occur during any stage of geothermal development whether it be field exploration and testing, production well drilling, construction, or power plant operation (Hess, et al., 1984).

Muds used for drilling may be harmful to water quality if they are allowed to enter either surface waters or groundwater aquifers. Many of these muds contain petroleum-based additives which can jeopardize the environment if accidentally leaked into surface water or groundwater aquifers (Brownell, 1981). To prevent contamination of surface waters, these substances, together with rock dust and the water used in the drilling operation, must be isolated from surface as well as groundwaters. Wells should be cased through potable groundwater horizons to prevent mixing of drilling fluids with groundwater. Blowouts can also pollute water, and blowout protection equipment should be required during the drilling of all geothermal wells except shallow temperature gradient holes. Sumps with an impermeable lining or steel tanks should be used to store drill cuttings and drilling fluids during drilling operation to ensure that these materials do not contaminate surface water (FERC, 1981).

Erosion and sedimentation associated with construction of drilling pads, roads, transmission lines, and power plants can effect the quality of nearby surface water. All problems of erosion and sedimentation can be minimized by careful site selection and engineering design, and the adoption of runoff prevention control measures.

The most serious water pollution problems, however, usually are associated with power production and the management of spent hydrothermal fluids.

In the case of a dry steam facility, relatively pure steam passes through the turbines before being condensed. The resulting condensate is injected into the geothermal reservoir so that it does not come into contact with surface and near surface groundwater. The injection well should be cased to ensure that no connection is established between shallow groundwater and the deep geothermal reservoir.

Hot water flash systems pose far more difficult water pollution problems than steam-dominated ones because wastewater from testing and production is far more abundant, and more water pollutants are generally contained in the geothermal fluid (Hess, et al., 1984). In a typical hot water flash plant, more than 75 million liters (20 million gallons) of wastewater per 100 MWe of generating capacity must be disposed of each day from the condensed effluent, and from brine that is not flashed to steam. This can be compared to the much smaller quantity of ca 28 million liters (7.5 million gallons) per day that is disposed of at a typical vapor dominated facility at The Geysers for each 100 MW of electrical generation (FERC, 1981).

Spent geothermal fluids from a hot water flash system are likely to contain large amounts of silica and/or calcium carbonate, together with potentially toxic amounts of NH_3, H_2S, Hg, B, and As (Hess, et al., 1984). However, the amounts of these materials vary a great deal from reservoir to reservoir, and often from well to well within a given reservoir. Because of this variability, several methods of disposing of the spent brines and condensate have been tested and used. These include: release to surface water, evaporation, surface spreading to shallow aquifers, desalination with subsequent water reuse, and injection to the producing aquifer or another suitable deep aquifer. The disposal method will depend upon the quality of the wastewater, local hydrological conditions, and environmental regulations. Of the various methods for wastewater disposal, injection to the geothermal reservoir is considered to be the most advantageous because if the injection well is properly constructed and cased, no pollutants in the water will come into contact with surface or shallow groundwater. In addition, injection may also help to maintain the long-term production of the geothermal resource and

lessen subsidence. Problems with injection can, however, occur from unusually high amounts of silica and/or calcium carbonate which may cause well-bore plugging by precipitation. The removal of silica and carbonates before injection through crystalization is being attempted today in the Imperial Valley of California, and, if successful, could remove one of the most serious injection problems.

All subsurface disposal of geothermal waters is regulated by the EPA's Underground Injection Control (UIC) regulation and by state drinking water programs developed pursuant to the Safe Drinking Water Act (Hess, 1984). The U.S. Geological Survey's Geothermal Resources Operational Order also provides strict regulations for injection on public lands to protect groundwater.

Because geothermal fluids used in direct applications generally contain much lower levels of dissolved volatile compounds and dissolved solids, major problems with the discharge of spent geothermal fluids have been kept to a minimum. Many of these waters are potable and can often be discharged to surface waters after cooling. High fluoride concentrations in spent geothermal fluids in Boise, Idaho, have, however, required that the fluids be injected. Again, the variable nature of geothermal fluids requires that each resource be evaluated on a site-by-site basis to determine the most environmentally sound disposal program.

5.4 Induced Seismicity

Many hydrothermal reservoirs are located in regions with a high frequency of naturally occurring seismic events. A significant environmental issue is whether the withdrawal and/or injection of geothermal fluids may enhance the rate of microseismic events, or even trigger a major earth movement. FERC (1981), however, concluded that "it is extremely unlikely that major seismic events could be triggered in this way." Experience with fluid injection in a number of nongeothermal situations has demonstrated that induced seismicity can be minimized or prevented by regulating injection pressures (FERC, 1981) (O'Banion and Layton, 1981).

5.5 Land Subsidence

The removal of large quantities of geothermal fluid from a geologic formation may result in land surface subsidence. Permanent and non-recoverable subsidence results from slow and long-term removal of fluids and from the compression of aquitards--such as clay, silty materials, or shale--above or below a reservoir. Such subsidence has been common following the withdrawal of water and oil. Subsidence has been observed at the geothermal field in Wairakei, New Zealand, where a minimum rate of subsidence of about 40 cm/year (15.6 in./year) has been measured.

Subsidence problems can often be mitigated through the injection of spent geothermal fluids which serve to maintain the pressures within a reservoir (FERC, 1981) (O'Banion and Layton, 1981) (Webb, et al., 1984). However, localized sinking around withdrawal wells and uplifting around injection wells may occur despite an injection program. Recognition of this fact may be pertinent to the scheduling of injection operations (FERC, 1981). Injection of spent geothermal fluids has not been practiced at Wairakei and could be expected to lessen the severity of the problem they are experiencing.

5.6 Water Supply

Geothermal power production may require the use of large amounts of water for cooling purposes At The Geysers and other vapor-dominated systems, water in the form of condensed steam has eliminated the need for an external source of water for cooling. Since, however, only approximately 20 percent of the fluid volume extracted is returned as condensate, an external water source

of nearly 110 million liters (30 million gallons) per day/per 100 MWe generated could be required if 100 percent injection were needed to maintain the resource.

The use of near surface groundwater for injection into a producing resource can seriously deplete such groundwater aquifers and the use of surface water for injection can present problems in maintenance of in-stream flows for aquatic biological resources as well as other beneficial uses of such water (Brownell, 1981).

Hot water flash power plants may also use condensed steam in the cooling system. However, as with a vapor-dominated system, if 100 percent injection is required, even flashed steam plants require a source of water to make up the required volume of injected fluid.

In a binary system, the geothermal fluid is injected directly to the geothermal reservoir once it has passed through a heat exchanger. Thus, 100 percent of the spent fluid is available for injection, but nothing is available for cooling the chlorofluorocarbon or isobutane used to drive the turbine, and an external source of water is required.

Preliminary designs for a 10 MWe demonstration binary power plant with an evaporative cooling tower indicate that about 22 l/sec. (346 gal/min) of make up water is required for cooling. At this rate, for an 80 MWe plant, 417 l/sec. (6.600 gal/min) or 13.1 x 10^6 m^3/year is required. This amount is substantially greater than that needed by alternative power generation systems and is a result of the low thermal efficiency of a geothermal plant. The availability of such large volumes of water may be a major problem in many arid areas where scarce water resources are needed for other purposes or all available water has already been appropriated.

The use of dry cooling towers which require very little water may provide a potential solution to the problem of water availability for cooling. The

efficiency and cost effectiveness of binary systems using dry cooling towers will be tested near Mammoth, California, by the Ben Holt Company in late 1984 (Ben Holt, 1984).

The development of Hot Dry Rock geothermal projects could require even greater amounts of water. Hot Dry Rock systems require large volumes of water for circulation through the system and for cooling. Preliminary data indicates that ca 10 percent of the water circulated is lost (Murphy, 1984). If such a system requires a volume equal to that of a flash plant, more than 7.5 million liters (2 million gallons) of water will be lost for every 100 MW of electricity generating capacity per day. Additional volumes of water will be required for cooling.

Generally speaking, direct heat projects will be designed as closed loops with injection to the producing formation, and will not require large amounts of exogenous water (O'Banion and Layton, 1981). In these systems, water will be needed only for the secondary closed loop which distributes exogenous water to end users; this would be a constantly circulating fluid that would only require minimal replacement of system losses.

A significant water concern for direct use project development is the potential for conflict between low- or moderate-temperature geothermal resources and groundwater supplies. All direct use projects that intend to withdraw or inject large amount of geothermal fluids will have to demonstrate a lack of adverse effects on groundwater supplies (O'Banion and Layton, 1981).

5.7 Solid Waste

The principal solid wastes accumulated are drilling muds and rock cuttings from drilling operations; precipitated solids (primarily silica and heavy metal sulfides) from spent geothermal fluids; removed scale from heat exchangers, flash tanks and piping; and sludge from the H_2S abatement process.

The safe disposal of solid wastes which result from geothermal drilling and plant operation is important from an environmental standpoint due to potential toxicity and the large volumes of wastes which may be produced as development proceeds. Composition of waste products will vary according to the physical and geochemical characteristics of the geothermal fluid, type of

energy conversion process, type of cooling, and method of H_2S abatement (FERC, 1981).

Solid wastes which contain hazardous substances should be contained and isolated from possible leaching to ground or surface water, or the leachate may be treated in order to remove hazardous elements and materials. Most wastes will have to be dewatered before they are removed to an approved disposal area. Toxic solid wastes may not, in most instances, be disposed of on site.

Solid wastes which contain recoverable heavy metals may become a valuable source of metals. Precipitated silica may also become a valuable material for the making of high strength concrete. If economical extraction processes can be developed for these materials, the cost of solid waste disposal could well be paid for by the value of the extracted materials (Toms, 1984).

Solid waste from direct use projects is usually limited to drilling mud and drill cutting, and should not pose a disposal problem.

5.8 Noise

A number of significant noise sources are associated with the development and utilization of geothermal resources. These sources include: the sound generated by heavy earthmoving and construction machinery, stationary diesel-powered engines and compressors used during well drilling, compressed air releases, the turbines, gas ejection, cooling towers at the power plant, and unmuffled venting of geothermal steam to the atmosphere. The noise level from venting unmuffled 150 psig steam from a 6 inch open valve can reach 131 decibels. Noise levels from drilling can reach approximately 90 decibels, and 84 decibels is common from a cooling tower for a 110 MWe facility (Norris, 1982).

If sensitive receptors such as homes, schools, hospitals, or outdoor recreation areas are located within one to five kilometers (one-half to three miles) of a geothermal development, site noise may lead to public annoyance and complaints.

Preliminary results of noise studies on various wildlife species at The Geysers indicate that moderately increased sound pressure levels (below 100 decibels), characteristic of developed areas, are not accompanied by drastic changes in wildlife communities. There is, however, some evidence that certain species may evacuate noisy areas, but there is no proof that noise is the causal factor (Leitner, 1978).

Noise shielding by terrain, forests, equipment, or the lip of the drilling pad can be used to reduce noise levels. The full use of demonstrated noise control technology can reduce most source noise levels to levels acceptable to most quiet rural communities at a distance of 1,000 feet (Norris, 1982). In fact, the noise from steam venting through a high efficiency drilling muffler can be reduced to 71 decibels while drilling noise can be reduced to 60 decibels. The noise level from a cooling tower for a 110 MWe plant was however reduced by only 5 decibels to 79 decibels, and must be considered to be the limiting factor.

The noise issue is generally insignificant at direct use geothermal sites. Reservoir pressures are low, and noise levels associated with drilling and testing are also generally much lower than those associated with drilling deep production wells for power generation. Once a direct use or heat pump system is on-line, the only potential sources of noise are pumps and the heat pump compressors.

5.9 Land Use

Land use in the vicinity of high temperature geothermal developments will most likely be changed by the construction of roads, ponds, drill sites, wells, above ground pipelines, powerlines, power plants, and by-product facilities associated with industrial development.

Such changes in land use can be most critical if they result in the loss of wildlife habitat. Critical to the Northwest are deer and elk winter range and reproduction areas, mountain goat ranges, and the habitat of rare, threatened, or endangered species (U.S. Forest Service, 1979).

Land use changes resulting from high temperature geothermal development can be expected to have a minimum effect upon agricultural and forest production as normally less than 20 percent of a typical 243 to 405 hectare (600 to 1,000 acre) lease hold necessary for the production of 100 MW of electricity is actually taken out of production by exploration and development activities. At The Geysers a direct vegetation loss of approximately .38 hectares (.93 acres) per MW has been experienced (Brownell, 1981).

Mitigating measures to reduce adverse impacts on land use from geothermal developments include actions such as land use planning, environmental evaluation, the use of buffers around critical habitats, sound engineering and construction processes, and the restriction of certain activities to noncritical periods.

Once a geothermal electric generating reservoir is no longer productive, all lands cleared for the purpose of utilizing geothermal energy can be returned to their original state in accordance with federal, state, and local requirements. Wells will be plugged and abandoned in accordance with state and federal regulations, and all foundations and equipment would be removed and either recycled or disposed of according to solid waste regulations (FERC, 1981).

In addition, although some geothermal development may have a negative effect on certain land uses, a positive effect can be obtained by providing greater public access to remote or isolated areas. Creation of new roads or the upgrading of existing roads can open new areas to multiple use development. Such roads can also serve as fire breaks to facilitate fire fighting in areas subject to grass, brush, or forest fires (U.S. Department of the Interior, 1973).

The most significant land use issues related to direct use exploration and development can be expected when geothermal reservoirs are located in or adjacent to areas designated as critical habitat areas, or in heavily urbanized areas, e.g., single family residential neighborhoods. Areas used for intensive agriculture may also present land-use impediments in terms of displaced crop lands although such displacement can be expected to be short term and be of significance only so long as the land is necessary during drilling. Land disturbances can be kept to a minimum utilizing slant drilling techniques, whereby up to ten wells can be completed from a single 1.5-2.5 hectare (3-6 acre) pad (O'Banion and Layton, 1981)

The problems associated with direct utilization, at least in urban areas, could be resolved by appropriate comprehensive land use planning in advance of direct use development. In Oregon, such comprehensive land use plans are mandatory for urban as well as rural areas (Allen, 1985).

5.10 Vegetation and Wildlife

The effects of geothermal energy development on biological resources can involve direct loss of habitat, disruption of fish spawning and nursery habitats, fisheries danger from water contamination, vegetation damage from airborne pollutants, and habitat disturbances from noise and human intrusion.

Direct loss of habitat will result from the construction of facilities such as roads, drilling pads, pipelines, power plants, and transmission lines. Such loss of habitat can be substantial at a given location, but should not amount to more than 53-65 hectares (130-160 acres) per 100 MW of generation capacity. Loss of habitat would be most significant if it involves loss of habitat of rare, threatened, or endangered organisms or if it disrupts big game migration routes (see section on Land Use). Loss of fish habitat can result from erosion and increase in the amounts of sediments in streambeds. This can adversely affect fish spawning and nursery habitat (Brownell, 1981).

Damage to aquatic life can occur from the discharge or spill of geothermal fluids, steam condensate, or drilling fluids containing such potentially hazardous substances as NH_3, H_2S, heavy metals, or fluoride into surface water (FERC, 1981).

Airborne pollutants, such as boron in the form of boric acid and H_2S, can severely damage or stress native trees, as well as cultivated shrubs and grasses, if mitigating measures are not taken (see section on Airborne Effluents).

Human intrusion, and accompanying noise and disturbances which are necessarily the result of geothermal exploration and development activities, can adversely affect wildlife use of adjacent habitat. Species such as nesting raptors and some predators may be particularly sensitive to these factors. Species which would be of critical importance in this respect to Pacific Northwest geothermal development would be the spotted owl, peregrine falcon, bald eagle, bear, cougar, and bobcat (U.S. Forest Service, 1979). Most other species, however, seem to adapt to the noise and disturbance (FERC, 1981).

Geothermal facilities should, wherever possible, be sited to avoid disturbance of important wildlife habitats such as state and federal refuges, wetlands, or desert areas with rare or endangered species. In addition, applicable baseline information should be gathered in all prospective resource areas to avoid siting facilities in sensitive areas. FERC, 1981, concluded that taking these precautions should ensure that no significant impact on terrestrial biota will occur. Webb, et al. (1984) concluded after studying 14 separate hydrothermal projects that impacts on land use and terrestrial ecology, when identified, were almost always minor.

The environmental effects of air and water pollution and mitigating measures have been discussed previously. However, if accidental discharges do occur which seriously impact wildlife or vegetation, operators should be required to compensate for such loss by making wildlife habitat improvements on adjacent lands (FERC, 1981).

The effects of direct use geothermal development on wildlife and vegetation should be minimal due to the fact that nearly all direct use development will occur in close proximity to urban centers where natural vegetation and wildlife will have been significantly altered prior to geothermal development.

5.11 Economic, Social, and Cultural Factors

5.11.1 Economic Effects

Economic impacts of geothermal development consist primarily of effects on employment and income, and can be divided into permanent effects due to creation of permanent jobs and temporary effects due to the influx of temporary employees involved in well drilling and facility construction.

Each 100 MW can be expected to result in approximately 15 direct permanent jobs and as many as 150 to 175 direct temporary jobs. On the basis of a $20,000 annual wage, and an employment multiplier of 2, each 100 MWe should result in a net income increase to the area of approximately $7 million (FERC, 1981).

In terms of construction and operation, the economic effects of direct use projects can be expected to have little impact upon a community. Few, if any, new permanent jobs would be created by a district heating system. However, the direct use of geothermal energy can be used as an economic tool to encourage industry to expand or locate in an area and could, in this way, result in a considerable number of new jobs.

5.11.2 Social Effects

Social effects may be caused by the influx of new residents into a developing area.

Given a family size of 3.5 for each new worker, the permanent population increase can be expected to be approximately 120 per 100 MWe. The temporary population would be nearly 1,200 per 100 MW of generating capacity. Of course, this assumes that all employees will be brought in from outside the area (FERC, 1981).

Such an increase in population will almost surely result in temporary insufficiencies in housing and public services. The impact on community infrastructures could be mitigated by contributions from geothermal developers on a cost-incurred basis for increased public service requirements, including schools. Another potential source of funding is the ability of counties to borrow funds from the federal government against future revenues they will receive from rental and royalty payments which will be made by developers (Public Law 94-579 Sec. 317(c)).

In some areas of geothermal development, transportation effects are likely to occur because of heavy equipment and commuting traffic. These effects will be greatest when large pieces of equipment are being moved in by heavy-duty vehicles and can result in increased noise, dust, and smoke, and potential hazards for persons living near the transportation routes. There may also be a need to reinforce or periodically repair roads and/or bridges over which heavy equipment must be transported. Permanent additional traffic should be limited to support businesses.

Adverse effects on transportation during construction can be mitigated by requiring all vehicles to meet air pollution as well as noise standards. Developers can be required to upgrade roads and dust problems can be controlled by watering or oiling (FERC, 1981). Hazards can be decreased by marking roads, requiring flagmen, and through the use of pilot vehicles.

5.12 Cultural Impacts

Aesthetic effects of geothermal development include visual, odor, and noise impacts.

Noise and odor, especially odor associated with H_2S emissions have been covered in previous sections.

Visual impacts, on the other hand, are extremely difficult to evaluate because the natural scenic value of the area must be judged, as must the desirability of altering that value.

A major source of visual impact will be drilling rigs, pipelines with expansion loops, generating facilities, cooling towers, steam plumes, and transmission towers and lines.

The effect of such facilities can be substantial in the Pacific Northwest where lands 50 to 60 miles distant are visible from numerous mountain peaks, and where such facilities will often have to be viewed against a backdrop of glacier-clad mountains, rushing streams, lakes, alpine meadows, and a broad spectrum of vegetation types (U.S. Forest Service, 1979).

If geothermal developers are required to take visual impacts into account during planning and design, facilities can be designed to meet applicable architectural standards. Thus, a plant and associated facilities could be made to blend harmoniously with its surrounding environment and have a reasonably pleasant appearance (U.S. Department of the Interior, 1973).

Archaeological and/or historic sites frequently are found either on or in the vicinity of many potential geothermal developments because of intensive use of thermal and mineral spring sites by both Indians and early settlers. Where such sites have not been adequately surveyed, and where a State Historic Preservation Officer (SHPO) determines that there is a high probability that an archaeological site exists, it is extremely important that an archaeological resource inventory be conducted before site development begins.

If a potential archaeological site is found, work should stop and test pits should be dug by archaeologists to determine the significance of the site. If it is determined that the site is not of significant historical importance, geothermal development may proceed as originally planned. If initial studies confirm that the site is of significant importance, the site should be avoided. If avoidance is impossible, the site should be fully explored, documented, and possibly excavated and curated, a very costly and time-consuming process. There is also a significant risk that if a site is be determined to be of great importance that development will not be allowed (FERC, 1981).

Buildings or other structures at a historic site should be examined by a historical architect before any actions are taken that might adversely effect them. Proper mitigation measures for a structure can involve moving the structure to another site, leaving and protecting the structure, or in some cases, tearing down after a photographic record and measured drawings have been made. If the structure is torn down, the site should be excavated as described above (FERC, 1981).

Areas of high geothermal potential may also be places of high religious significance to various Indian groups and are protected through provisions of the American Indian Religious Freedom Act (Public Law No. 95-341, (United States Forest Service, 1981)). If development is contemplated on federal or state lands, appropriate land management agencies should be contacted concerning the existence of American Indian Religious Freedom Sites. If such sites exist in the immediate vicinity of the proposed work, representatives of the Indian people should be contacted so that location of such sites can be determined and significance and usage patterns established.

The use of such sites is guaranteed to the Indians by statutes and only through closely working with Indians can conflict be avoided or minimized.

The direct use of geothermal energy can have many of the same cultural effects that electrical generation can be expected to have. Because many direct use projects occur near hot springs, the historic use of the springs may be significantly altered. Conflict with American Indian Religious sites can, however, be expected to be minimal as most such sites are located in remote areas, at considerable distances from population centers.

5.13 Conclusion

Geothermal development, as with any major development, can pose serious threats to the environment. Among these are the release of air and water effluents, induced seismicity, land subsidence, water supplies, solid waste, noise, and land use. The geothermal industry has, however, benefited from the fact that most geothermal development post dates the passage of the National Environmental Protection Act, and the new geothermal industry has had to meet the challenge of growing up in a period of high environmental awareness. Because of this, regulatory agencies as well as geothermal developers have

been forced to adopt policies and procedures which ensure a high level of environmental protection.

Providing such protection, however, has not always been easy. The site-specific nature of geothermal resources does not allow for broad generalizations about the environmental risks of geothermal development. The way in which geothermal resources are developed, however, from surface geological and geophysical exploration to drilling, to field development, to facility construction, provides the regulatory agency as well as the developer the flexibility which is needed in order to provide adequate environmental protection in a cost-effective manner. Experience has shown the importance of early environmental planning, baseline data gathering, monitoring of ongoing activities, and the timely use of mitigation measures (Webb, et al., 1984).

Technological advances also have played a major role in ensuring that geothermal development meets environmental standards. H_2S abatement systems continue to be developed, along with methods for controlling boron and other airborne effluents.

Silencers and mufflers continue to reduce noise emitted from drilling operations, the venting of wells, and from turbines and cooling towers.

Proper injection of condensate and brine can greatly reduce land subsidence and the risk of fouling surface water or near surface groundwater (Webb, et al., 1984).

Whether a need exists for even greater protection is yet unknown, but if greater protection is deemed to be necessary, regulatory agencies and the geothermal industry have established a sound framework upon which to build.

TABLE 5.3 - GEOTHERMAL-VAPOR DOMINATED SYSTEM

ENERGY SYSTEM:

SIZE o
- o 15% conversion factor
- o 75% capacity factor
- o Produces 2.47 x 10^{12} Btu per year
- o Unit 12 of Pacific Gas & Electric Geysers generating system

DESCRIPTION
- o Steam is purchased from the Geysers field and is used to drive a turbine generator with condensate water used for cooling. No abatement procedures are used at the generating plant; however, the steam distribution system includes a centrifugal axial separator. Furthermore, H_2S abatement measures are planned for implementation beginning with unit 13.

COMPONENTS
- o Production wells
- o Gathering system
- o Steam distribution system
- o Turbine-generator
- o Condensate
- o Heat rejection system
- o Gas ejector system
- o Electrical system and controls
- o Waste purification

ENVIRONMENTAL CONCERNS
- o Hydrogen sulfide (H_2S) is toxic, has odor--but control tech-

RESOURCES USED:

FUEL	
Steam	6.7 x 10^{12} btu's
LAND	
Permanent	31.2 - 62.4 acres
Undisturbed	249.6 - 280.8 acres
WATER	Acre-Feet
Water vapor input	1,960
Water vapor discharged to air	1,640
Water reinjected to wells	320
PERSONNEL	Workers
Construction (man-years) generating plant	57.43

RESOURCES USED:

well-field	NA
total	NA
Operation & maintenance	
generating plant	NA
well-field	NA
total	4.97

RESIDUALS AND PRODUCTS:
(Per 10^{12} Btu Produced)

AIR POLLUTANTS(1)		
Carbon dioxide	250-26,000	(11,160)
Ammonia	16-1,800	(660)
Methane	13-1,500	(660)
Hydrogen sulfide	5-1,500	(764)
Arsenic	NA	(8 x 10^{-4})
Boron	NA	(1.7)
Mercury	NA	(5 x 10^{-3})
Hydrogen	6-120	(83)
Water vapor	NA	(2.9 x 10^6)
Nitrogen, argon	4-410	(2.9 x 10^6)
WATER POLLUTANTS(2)	Tons	
Carbonates	81-210	(249)
Ammonia	62-104	(86)
SO_2	NA	(1.2)
Sulfate	87-260	(76.2)
Sulfur	NA	(4.9)
Nitrate	0.04	(0.06)
Chloride	2	(2.0)
Calcium	NA	(3.1)
Magnesium	NA	(0.6)
Silicon	NA	(2.2)
Boron	44-89	(10.0)
Total solids from evaporation	NA	(107.7)
Organics and volatile solids	NA	(120.0)
Water	NA	(-320 acres-feet)
RADIATION(1)	Ouries	
Air		
Rn-222	41	

TABLE 5.3 (Continued)

ENERGY SYSTEM:

nologies are available
- o High noise levels
- o Disposal of excess steam
- o Emissions highly site, reservoir, and time dependent
- o Conflicts with existing community lifestyles

(1) Site specific for The Geysers field. Assumes no abatement measures.

(2) No treatment involved, reinjected through wells.

(3) Values in parentheses indicate actual emissions from The Geysers field operations.

(SOURCE: FERC, 1981)

RESIDUALS & PRODUCTS:

HEAT	Btu's
Waste heat (discharged to air)	5.4×10^{12}
NOISE	**Decibels (A)**
Well drilling	75-80 at 50 ft.
mud drilling (60 days/well)	85-120 at 25 ft.
air drilling (30 days/well)	
well cleaning; open well (3-6 days)	118 at 50 ft.
well testing: open well (14 days)	118 at 50 ft.
rock muffler	89 at 50 ft.
well bleeding (variable)	65-86 at 5 ft.
well blowouts (infrequent)	118 at 50 ft.
Construction of plant construction operations (1-2 yrs)	70-90 at 50 ft.
Plant operation (20-30 yrs)	
muffled steam line vent :(intermittent)	90 at 100 ft.
jet gas ejector (continuous)	84-117 at 5-10 ft.
steam line separator (continuous)	80 at 25 ft.
steam line breaks (brief, infrequent)	100 at 50 ft.
cooling tower (continuous)	80-90 at 5-10 ft.
turbine generator building (continuous)	70 outside
ENERGY	
Electricity	2.93×10^{8} kWh

TABLE 5.4 - GEOTHERMAL-FLASH INJECTION SYSTEM

ENERGY SYSTEM:

SIZE:

- o 50 MWe (net) power output
- o 10.1×10^6 lb/hr brine flow rate (fuel) to plant at 338°F/115 psia
- o 13 production wells
- o 6 reinjection wells
- o 8.69×10^{10} lb/hr brine/cooling water flowrate reinjected at 220°F/315 psia
- o 10 acres plant site
- o 30 years plant life
- o .75 capacity factor
- o 1.1211×10^{12} Btu annual power output
- o 8-11% thermal conversion efficiency for 375°F brine

DESCRIPTION

- o Geothermal brine is drawn through production wells and transported to the power plant. Steam is produced from the brine by reducing the brine pressure below its vapor pressure. This process, known as flashing, is performed twice. The excess brine is reinjected through reinjection wells. The noncondensable gas portion of the steam is treated with an H_2S scrubbing process and is released to the atmosphere (estimated H_2S

RESOURCES USED
(Per 10^{12}) Btu Produced)

FUEL	
Geothermal brine, 338°F, 115 psia	2.958×10^7 tons
LAND	
Wells and islands	3.57 acres
Plant size	8.9 acres
CHEMICALS	Tons
Alkali or scrubber	NA
PERSONNEL	Workers
Field construction	NA
Field operation	NA
Plant construction	NA
Plant operation	NA

RESIDUALS AND PRODUCT
(Per 10^{12} Btu Produced)

AIR POLLUTANTS	
Hydrogen sulfide[a]	19.4
Ammonia	98.8
Methane	580
Carbon dioxide	35,500
Arsenic	NA
Boron	NA
Mercury	0.1
Hydrogen	NA
Nitrogen, argon	NA
Water vapor	4.3×10^6
WATER POLLUTANTS	Tons
Carbonates	NA
Ammonia	NA
SO_2	NA
Sulfate	NA
Sulfur	NA
Nitrate	NA
Chloride	NA
Calcium	NA
Magnesium	NA
Silicon	NA
Boron	NA
Dissolved solids	NA
Water (tower blowdown)	1.76×10^5
Total brine	2.53×10^7
Total suspended solids	NA
Nutriants	NA
RADIATION	
Air	Curies
RN-222	7.3
Other radionuclides	NA

TABLE 5.4 (Continued)

removal of 99%). Condensate steam is used for cooling with excess condensate employed for continuous blow-down and reinjected with the excess brine.

COMPONENTS
- o Production wells and islands
- o Reinjected wells and islands
- o Distribution system
- o Steam system
- o Brine system
- o Cooling system
- o H_2S scrubber

ENVIRONMENTAL CONCERNS
- o Releases of noncondensable gases
- o High noise levels
- o Potential groundwater contamination
- o Land subsidence
- o Increased seismic activity
- o Alteraation of runoff patterns
- o Habitat disruption
- o All factors are highly site specific

NOISE	Decibels
Well construction	Intermittent high intensity
Well operation	Intermittent high intensity
Plant construction	medium intensity
Plant operation	low intensity

ENERGY PRODUCT	kWh
Electricity	2.93×10^8

(a) Without sulfur removal system.

SOURCES: FERC, 1981

CHAPTER 6

Geothermal Resource Ranking Methodology

6.0 GEOTHERMAL RESOURCE RANKING METHODOLOGY

6.1 Introduction

For the Pacific Northwest geothermal assessment study, it is desirable to find a technique to evaluate all resources on a common basis to allow resource sites to be ranked. In many cases, sufficient information for detailed engineering-economic analyses is not available. Our approach, therefore, is to create a ranking methodology to estimate the developability of low and high temperature resources.

The analytic method is based on a weighted variable evaluation of geothermal resource favorability. This technique is similar to one developed by McClain (1980), and has been modified to allow comparative ranking of geothermal sites in the Pacific Northwest. A significant improvement has been made to allow for the large uncertainties that surround geothermal resource assessment. Hirakawa and Arisaka (1981) have used the Monte Carlo technique to address uncertainty in an exploration program for a Japanese geothermal field. We have chosen a method simpler in computation and interpretation than the Monte Carlo technique, and yet one which is well matched to the level of data that is typically available.

Our analysis is generic to allow relative ranking of resources. It divides the characteristics that determine geothermal development potential into three broad concerns: resource, engineering, institutional and environmental factors. The methodology is described in detail below.

6.2 The Method

Our method for ranking begins with a listing of factors that are related to the developability of a resource for electric power generation or district heating applications. Numerical estimates are given to each variable to indicate its relative importance in the assessment. Estimates are based on a Delphi approach using "expert opinion" of geologists and engineers. The characteristics and their weights were reviewed and altered over a six month period with considerable input by the Technical Review Committee.

The variables and their weights are presented in Tables 6.1 and 6.2. The values assigned to individual variables have been selected to approximate the various attributes a firm might consider in their geothermal exploration program.

TABLE 6.1 - High Temperature Ranking Criteria

	Characteristic	Numerical Weight
I.	Resource	
	Estimated Reservoir Temperature	14
	Potential for High Permeability	14
	Age and Type of Volcanism	12
	Estimated Drilling Depth	8
	Prospect Areal Extent	4
	Drilling Difficulty	4
	Heat Flow	4
	Total	60
II.	Engineering	
	Distance to Powerlines	10
	Terrain of Powerline Corridor	6
	Resource Site Accessibility	4
	Terrain of Development Site	4
	Distance to Heating Load	3
	Annual Heat Load/Density	3
	Total	30
III.	Institutional/Environmental	
	Special Regulatory/Environmental Concerns	16
	Land/Resource Management	8
	Percent Leased for Exploration	6
	Distance to Legally Designated Areas	5
	Air/Water Concerns	5
	Total	40
	GRAND TOTAL	130

TABLE 6.2 - Direct Utilization Ranking Criteria

	Characteristic	Numerical Weight
I.	Resource	
	Known Temperature of Fluids	11
	Prospect Areal Extent	8
	Total Flow Rate	7
	Local Gradient	6
	Drilling Depth	7
	Estimated Pumping Depth	5
	Preferred Geothermometer Temperature	4
	Drilling Difficulty	2
	Total	50
II.	Engineering	
	Annual Heat Load/Density	22
	Distance to Heating Load	8
	Heating Degree Days	6
	Least Cost Heat Energy	8
	Resource Site Accessibility	2
	Terrain of Pipeline Corridor	2
	Trenchability of Pipeline Corridor	2
	Total	50
III.	Institutional/Environmental	
	Special Environmental Regulatory Concerns	12
	Land/Resource Management	7
	Air/Water Concerns	5
	Distance to Legally Designated Areas	3
	Owner Attitude Toward Development	3
	Total	30
	GRAND TOTAL	130

For each of the variables a dependent variable is selected that allows a correlation process to determine the relative score for each resource site for each of the above characteristics. A perfect resource score is 130. Table 6.3 presents the dependent variables and the measurement units used.

TABLE 6.3 - Dependent Variables Used for the Correlation Procedure

Measurement Units	Dependent Variable
Degrees Centigrade	Estimated Reservoir Temperature
Faulting/Existence of Fluids	Potential for Permeability
Type/Composition of Rocks and Age	Age and Type of Volcanism
Depth in meters	Drilling Depth
Estimated Rock Type	Drilling Difficulty
Surficial Area - square kilometers	Prospect Areal Extent
Milliwatts Per Square Meter	Regional Heat Flow
Slope of Terrain	Terrain of Powerline Corridor
Kilometers	Distance to Powerlines
Access Road Type	Resource Site Accessibility
Number of Terrain Concerns	Terrain of Development Site
Kilometers	Distance to Heating Load
Degree of Urbanization	Heat Load Density
Private/Federal/Mixed	Land/Resource Management
Number of Special Concerns	Special Environmental Concerns
Decimal Fraction Leased	Percent Leased for Exploration
Kilometers	Distance to Legally Designated Areas
Number of Pollutants Above EPA Regs	Air/Water Concerns
Positive or Negative	Owner Attitude Toward Development

Based on geologic and engineering information, relationships between the dependent variables and the assessment criteria are established. Graphic curves are produced and then fit by linear and non-linear curve-fitting procedures to determine the fractional score of the ranking variables. This determines the points scored for any resource characteristic from the total available. Linear relationships are fit with a simple least squares regression line. Non-linear relationships are fit with a seven degree polynomial regression. This is expressed as:

$$Y = B0 + B1 \times X + B2 \times X^2 \ldots + B7 \times X^7$$

Where: Y = the fractional score for the characteristic (0 - 1.0)

B0 = the regression constant

B1 - B7 = Regression coefficients determined from correlation.

In all cases R-squared is greater than .99. The score from the correlation procedure is always between zero and one, so that the final score is similarly

constrained. Also, a score of zero for reservoir temperature, permeability and drilling depth results in the total assessment being multiplied by that factor-- a zero score overall. Figures 6.1 through 6.38 show the graphic relationships between the ranking criteria, and the fractional scores of each characteristic. Each curve is briefly described below.

6.3 Description of the Curves

The sites that remain after application of the screening criteria described in Chapter 2 are then ranked using a computerized version of the ranking methodology called GEORANK. Resources with geothermometers in excess of 90 degrees centigrade are ranked as high temperature resources, others are ranked as low temperature ones.

The purpose of ranking each characteristic is to determine a unique value for this characteristic. This is determined by the use of a correlation variable. After estimates have been made for values of the independent variables for each resource, they are then correlated from the mathematic fits to these curves to determine the dependent value used to estimate the fractional score for each ranking characteristic. Each of the final scores is then summed for a final score for that site. Resources with the highest scores are ranked as those with the greatest development potential.

6.4 The Uncertainty Problem

Unfortunately, the score that results from the above procedure is often based on highly uncertain estimates due to the 'blind' nature of geothermal resources. Often the exact location or the existence of a high temperature resource may be uncertain even when extensive surface geology and geophysical studies are completed. A good example of this problem is illustrated by the Marysville well drilled near Helena, Montana. Based on a large volume of data and informed opinion, it was expected that a magmatic intrusion would be located with high temperatures. A hydrothermal system was found instead, with temperatures of only about 100°C. The estimated flow rates that might be available are seldom known and can lead to project failure as illustrated by DOE's Baca, New Mexico project. Reservoir volume, recharge rate and prospective lifetime are almost always unknown.

Drilling helps define the resource, but the costs can be high and the payoff potentially low. The payoff geothermal wells is less than that for hydrocarbon exploration. Whereas an oil drilling program might be profitable under a wildcat program that produces from one in ten wells, geothermal programs can seldom afford such risks. As an example, a geothermal well drilled to a depth of one kilometer might cost $350,000. Therefore, a million dollar drilling program for three holes with 60 percent confidence in finding suitable fluids still has a 6.4 percent chance of total failure. Furthermore, this risk is only one uncertainty in the project, i.e., the drilling confidence factor. Typically in geothermal field development, uncertainty exists in several aspects of the project. An appropriate evaluation of uncertainty would account for the cumulative uncertainties and their effects on project favorability.

Geological evaluations involving uncertainty typically use Monte Carlo simulations with triangular probability distributions. This method is accurate but is computationally tedious, often requiring thousands of iterations for reasonable accuracy. Here, a simple cumulative error model is used to evaluate uncertainty. The root mean sum of the squared errors is used with the implicit assumption that the residual errors of each function are serially independent. It is expressed by the following equation:

$$\text{Uc prob} = \sqrt{\sum_{i=1}^{n} \left(\frac{dFS - dx_i}{dx_i} \right)^2}$$

Where: Uc prob = the <u>most likely</u> uncertainty in the assessment score.

dFS = change in the fraction score.

dx_i = change in parameter "x " examined.

n = number of uncertainties examined.

The specification does not require that maximum and minimum estimates be made. A certainty level is given for each estimate of the seven resource variables and uncertainty is assumed to be distributed normally about the most likely figure. The number that is used for ranking purposes is the <u>most probable</u> minimum score. This assumption reflects the economic reality that firms investing in a risky venture are often more concerned with the worst case than

they are about the maximum project payoff. This method has been found effective with the level of data often encountered in preliminary geothermal site assessment.

6.5 The GEORANK Program

A computerized version of the ranking methodology was written for an IBM P.C. microcomputer to speed the ranking process. This program has numerous advantages over a manual calculation. It is fast and accurate, and with available data, a site can be evaluated in as little as three minutes. Data entry is automatic and calculations are reliable and error-free. A description of the program, user documentation, and the program listing are provided in Appendices 8 and 9.

Data for program entry are entered on a special form. One form is for high temperature resources and another is for direct utilization resources. Instructions for filling out the data input sheets are provided in Appendices 8 and 9 as well. To illustrate their use, sample high temperature and direct utilization resource sheets are shown in Figures 6.39 and 6.40. The resulting GEORANK runs are shown in Figures 6.41 and 6.42. Note that the program automatically correlates input variables and resource uncertainties, and estimates the most likely score, the probable uncertainty and the likely minimum score.

The number used to rank a resource is the normalized minimum score which is the <u>likely minimum score</u> divided by the <u>total</u> possible points (130). This gives an advantage to resources that are better-defined. This is a reasonable assumption since resource definition can be an expensive process (see Chapter 6). Use of the minimum likely score is consistent with the exploration philosophy described above, where firms are more concerned with the worst possibilities than the best. All Pacific Northwest geothermal resources were ranked on this basis to estimate their relative development potential. The results of the ranking are described in Chapter 9.

HIGH TEMPERATURE GRAPHS

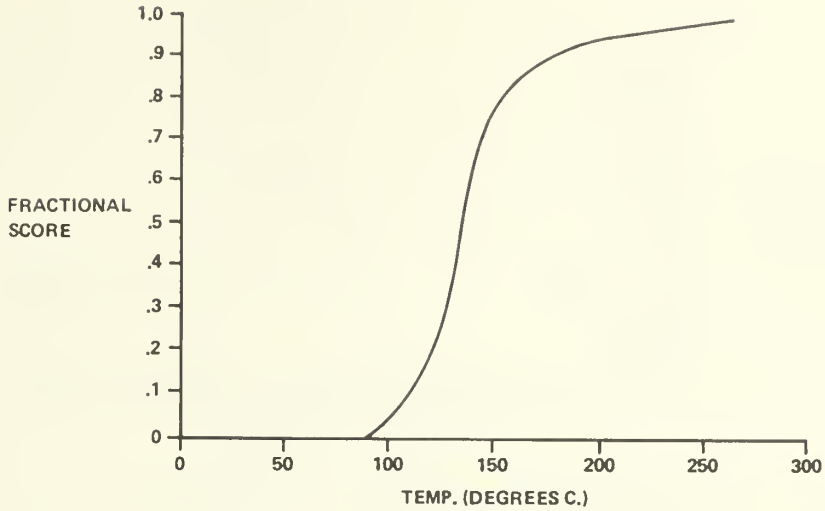

Figure 6.1 - Estimated Reservoir Temperature

This curve is a generalization of three separate curves representing wellhead, binary, and flash steam generation technologies. All three curves were based on the theoretic electric generation from each configuration at the indicated reservoir temperature (Ryan, 1983; Bloomster and Maeder, 1980). The curve produces a fractional score of zero at 90°C and unity at approximately 250°C.

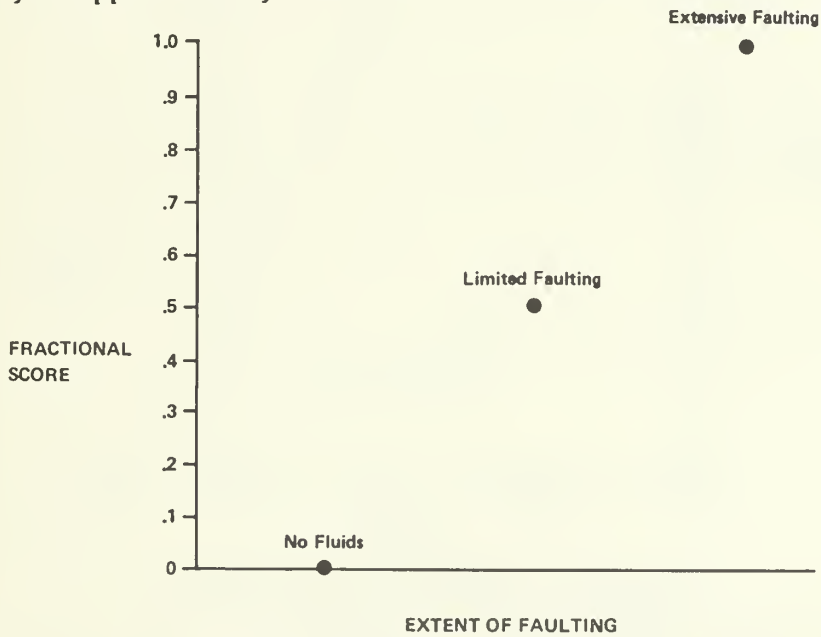

Figure 6.2 - Potential for High Permeability

This characteristic is very important since it represents the capability of obtaining the geothermal fluids from the reservoir. However, the geological information available to analyze this characteristic does not lend itself to a continuous function. Therefore, the correlation characteristic is greatly simplified. Reservoir systems that are judged to contain extensive faulting will receive full points (fraction score of 1.0), those with limited faulting will receive half points, and those with no known faulting, a score of zero.

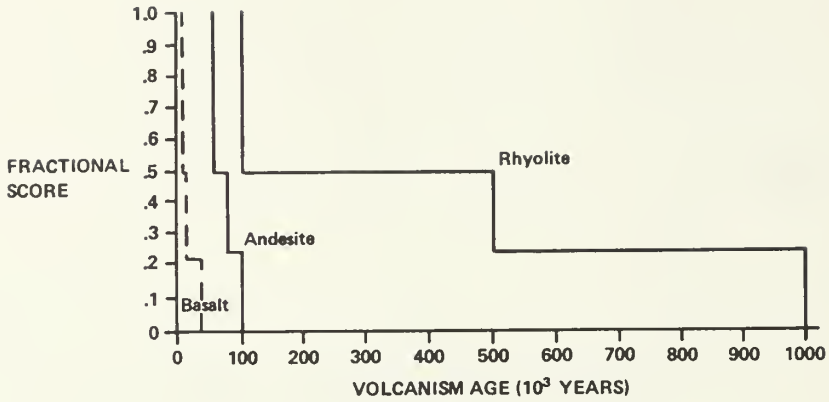

Figure 6.3 - Age and Type of Volcanism

Age and type of volcanism is used as a proxy for probability of locating a geothermal resource. The function is a composite of steps for basalt, andesite and rhyolite deposits used to construct this graph. Ranges of rock age and type yield varying fractional scores.

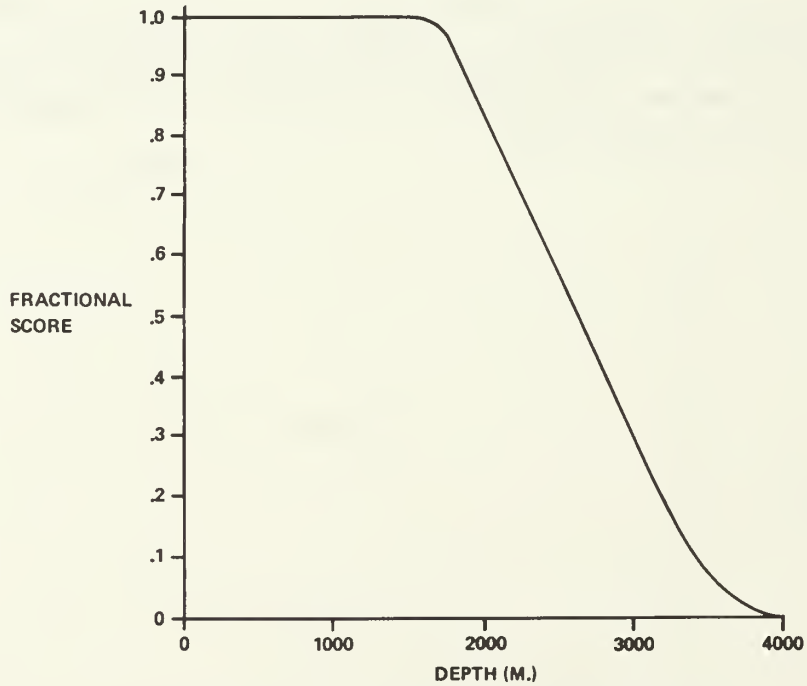

Figure 6.4 - Estimated Drilling Depth

This curve reflects the fact that while deep drilling is costly and hazardous, shallow drilling projects are of little consequence in high temperature geothermal exploration. The drilling depth fractional score is constant at a value of 1.0 until a depth of approximately 1,200 meters. The score then drops rapidly in a negatively linear fashion until 3,200 meters with a score of approximately .1 reaching zero at 4,000 meters.

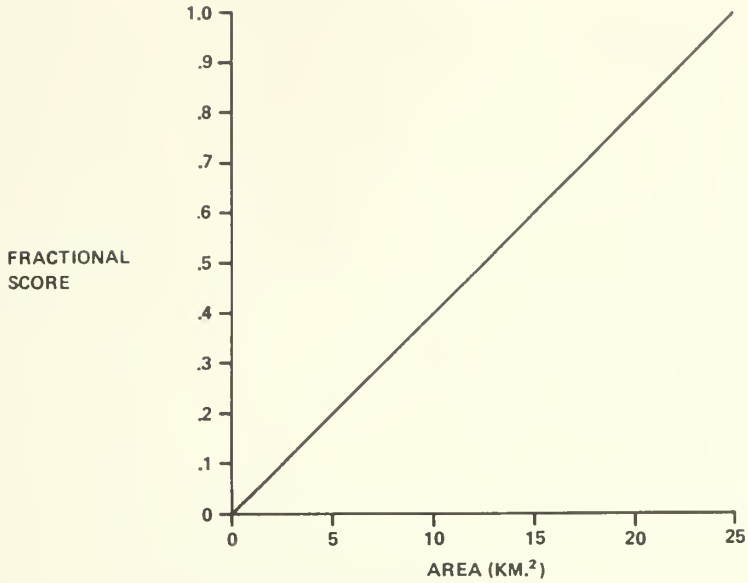

Figure 6.5 - Prospect Areal Extent

The fractional score for areal extent is related by a positive linear function. Simply, the greater the prospect area, the higher the fractional score. In this case, the surficial area is used as an indicator for probable reservoir size.

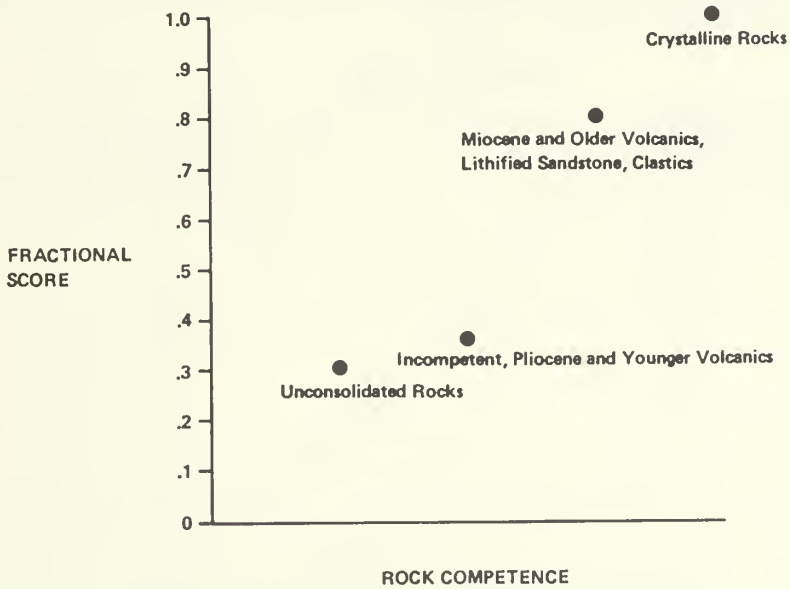

Figure 6.6 - Drilling Difficulty

This variable has four possible fractional scores as listed below:

> Crystalline Rocks (1.00); Miocene and Older Volcanics, Lithified Sandstone and Clastics (.8); Pliocene and Young Volcanic, Incompetent Rocks (.35); Unconsolidated Rocks (.3).

The rationale here is that more competent rocks, although slower to drill through, represent a more certain drilling environment. Voids, and loss of control are significant problems in young volcanic deposits and unconsolidated rock types.

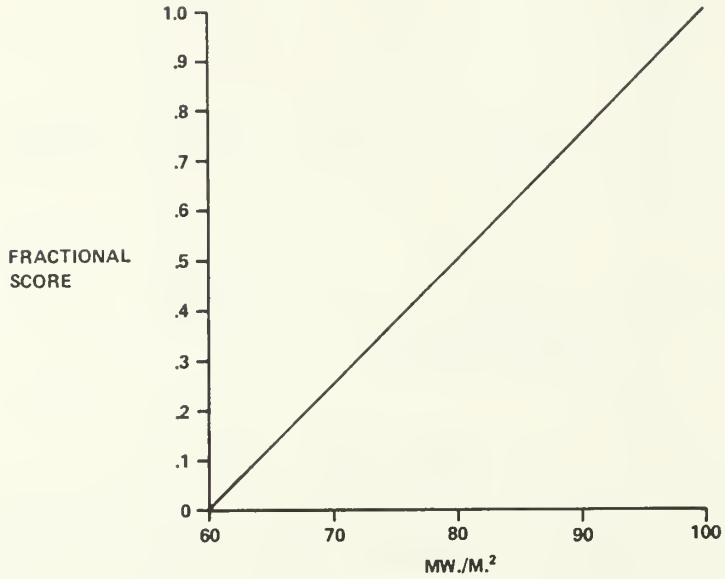

Figure 6.7 - Regional Heat Flow

The regional heat flow is a positive linear function. A fractional score of zero is assigned to a heat flow of 60 MW/m^2, 100 MW/m^2 generates a fractional score of 1.0. The lower number was set to reflect above background levels and the higher was set to the highest heat flows encountered in the Pacific Northwest.

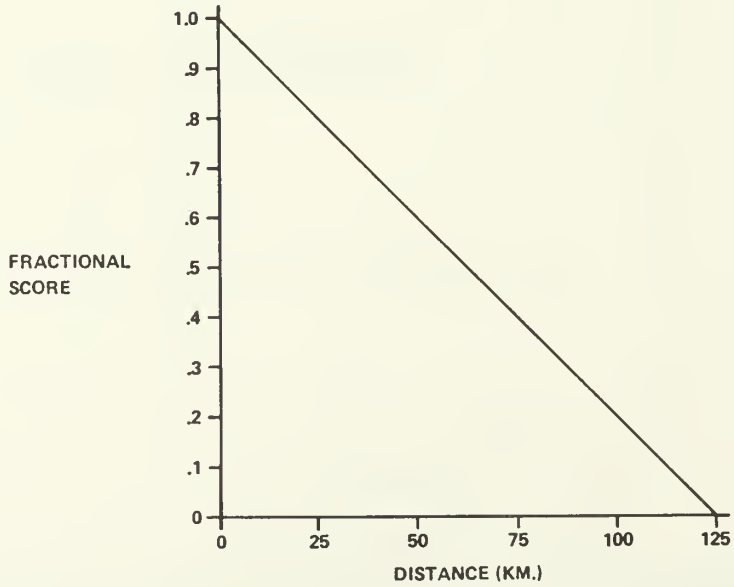

Figure 6.8 - Distance to Powerlines

In this characteristic powerlines of interest are 12 kv to 230 kv. The function is linearly decreasing from the maximum score to a score of zero at a distance of 125 km.

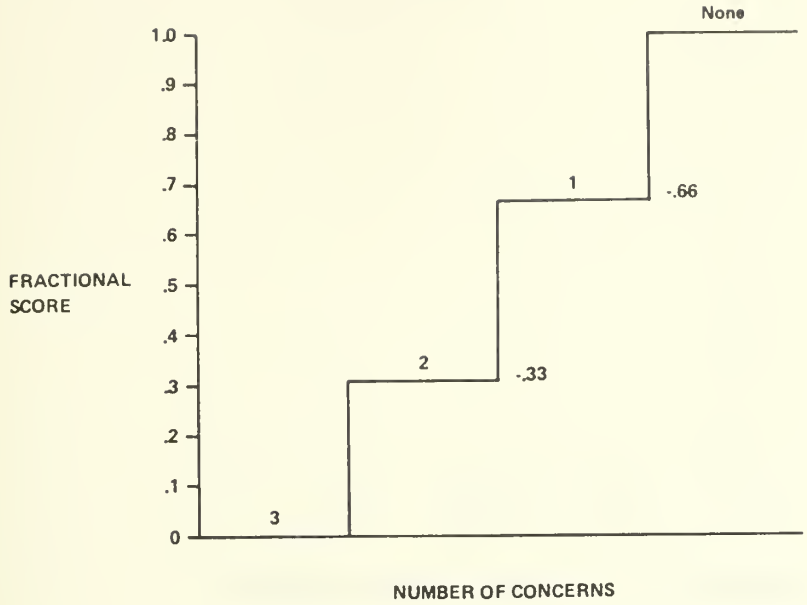

Figure 6.9 - Terrain of Powerline Corridor

The fractional score for the terrain of powerline corridor is described in this graph through a simple step function. The number of terrain-related concerns is used to produce the fractional score.

Areas of Concern

1. Terrain: Slope Greater Than 30%	4. Agricultural Lands
2. Limited Access	5. Rivers/Wet Lands
3. Federal Lands	6. Recreational Lands

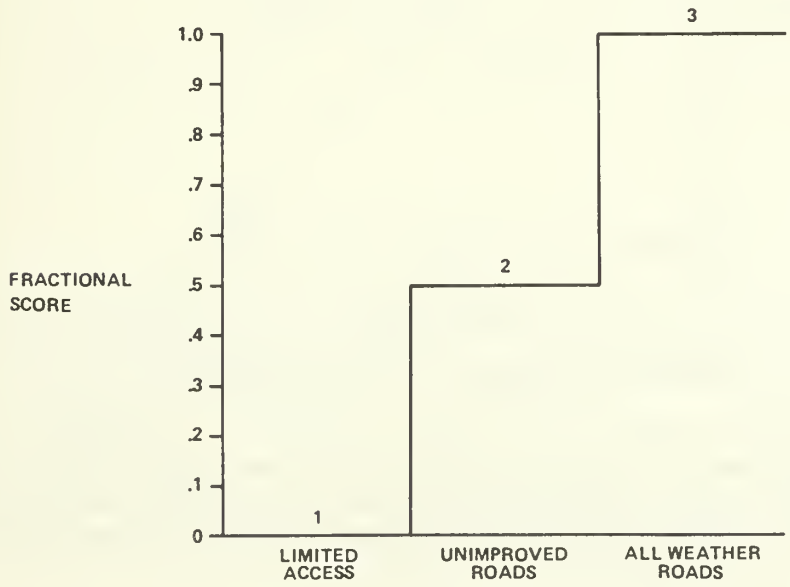

Figure 6.10 - Resource Site Accessibility

Site accessibility depends on road conditions. Improved roads receive a score of 1.0. Unimproved roads receive a score of 0.5. A site with no road access receives a zero score.

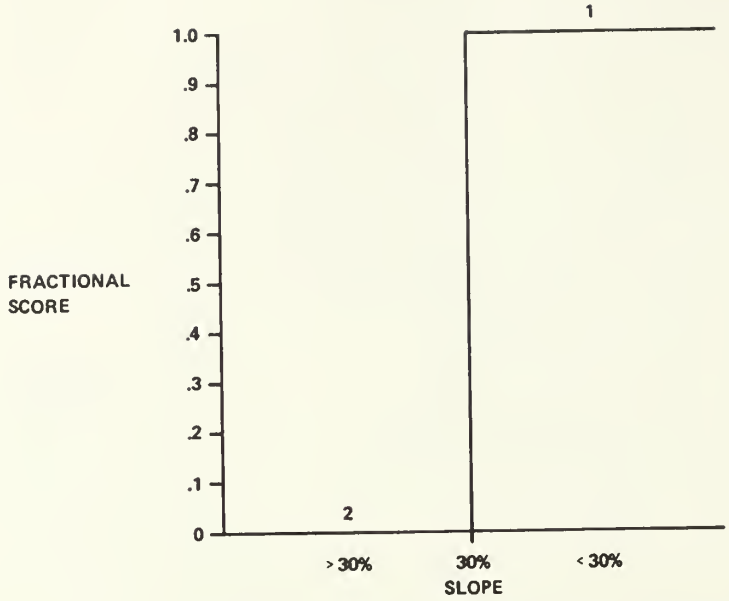

Figure 6.11 - Terrain of Development Site

Development feasibility is assumed to be related to the slope of the terrain on site. Sites with slopes greater than 30 degrees receive a zero score, those with slopes less than this figure receive full points.

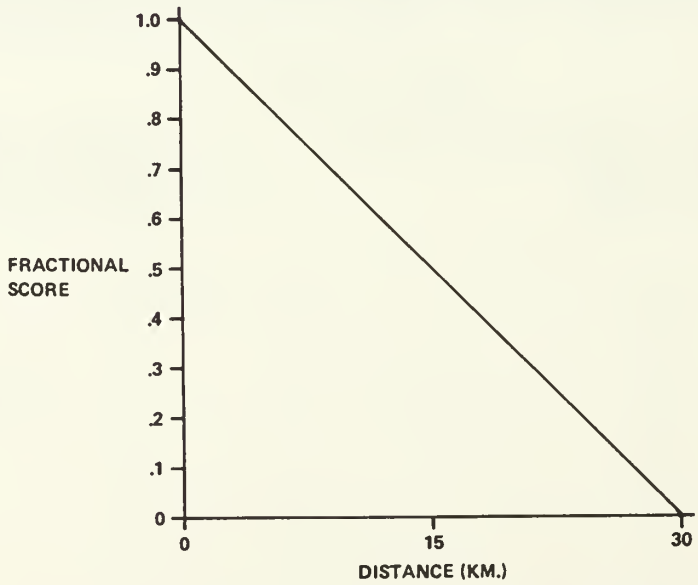

Figure 6.12 - Distance to Heating Load

Project costs for heat distribution are strongly affected by the distance between the heating load to the geothermal resources. The HEATPLAN program (Eliot Allen, 1984) was used to develop this relationship. Thirty kilometers was judged to be the maximum distance over which low temperature geothermal heat might be economically transported to a high load/high density market.

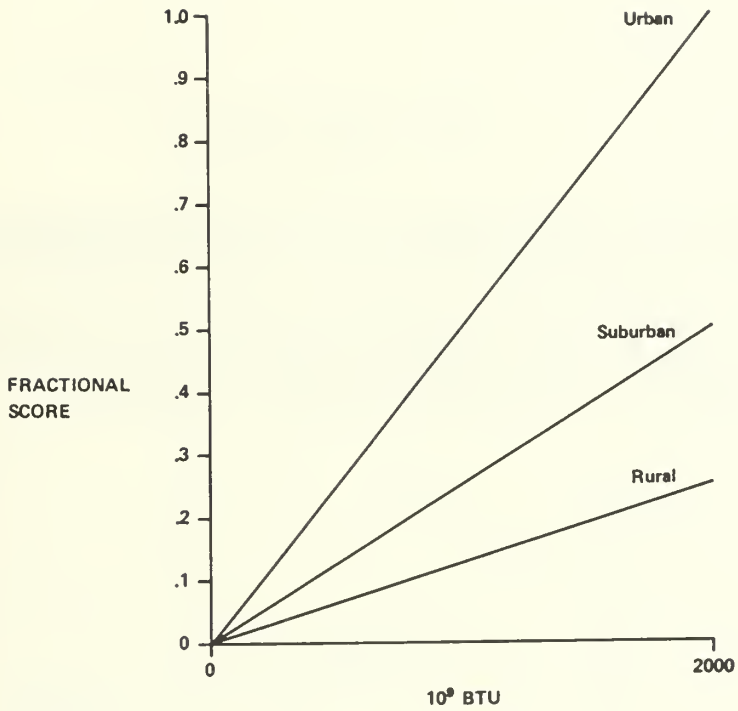

Figure 6.13 - Annual Heating Load/Density

This graph is a composite of three linearly increasing functions representing the rural, suburban, and urban heating load density. The expected annual heating load ranges are zero to 2,000 x 10^9 Btu. Rural, suburban, and urban functions yield scores from 0 to .25, .50 and 1.0, respectively, for the maximum heating load.

Population

Urban	-	50,000+
Suburban	-	50,000 - 1,000
Rural	-	1,000 -

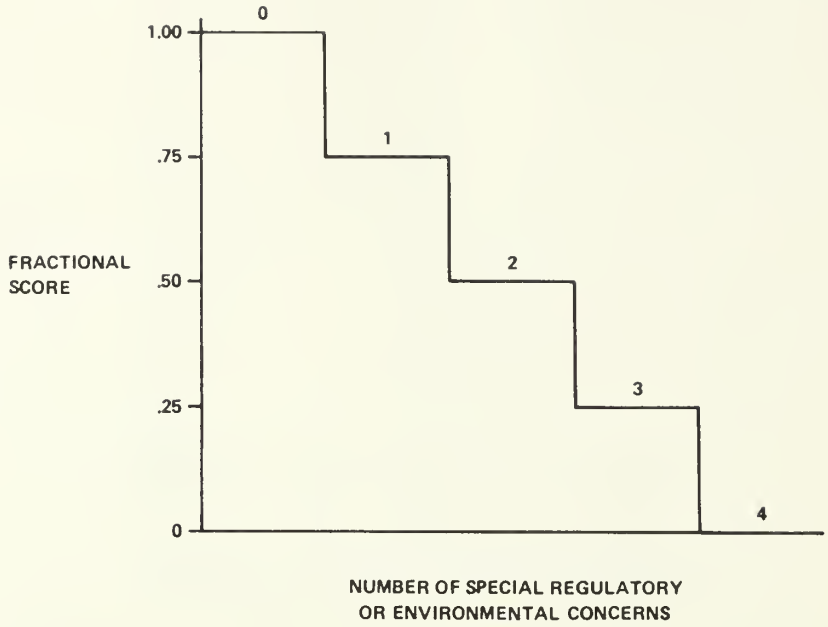

Figure 6.14 - Special Regulatory/Environmental Concerns

The relation between fractional score and number of special regulations or environmental concerns is given by a step function. No special concerns receives a maximum score. One concern receives 0.75 points. Two or three concerns receive fractional scores of 0.5 and 0.25, respectively, and four or more concerns receives a zero score.

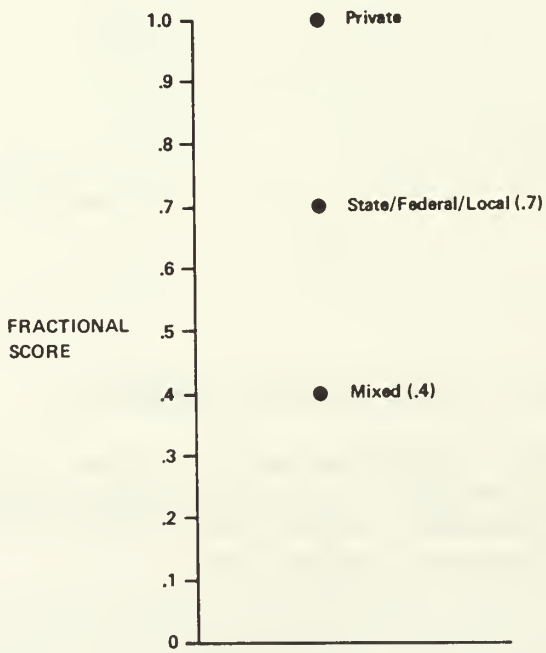

Figure 6.15 - Land/Resource Management

This variable assigns a value of 0.4, 0.7 and 1.0 to mixed; single government ownership, state/federal/local; and privately-owned lands, respectively. The reasoning is that private ownership presents the fewest problems to geothermal development, while mixed ownership/management presents the greatest time delays and associated difficulties.

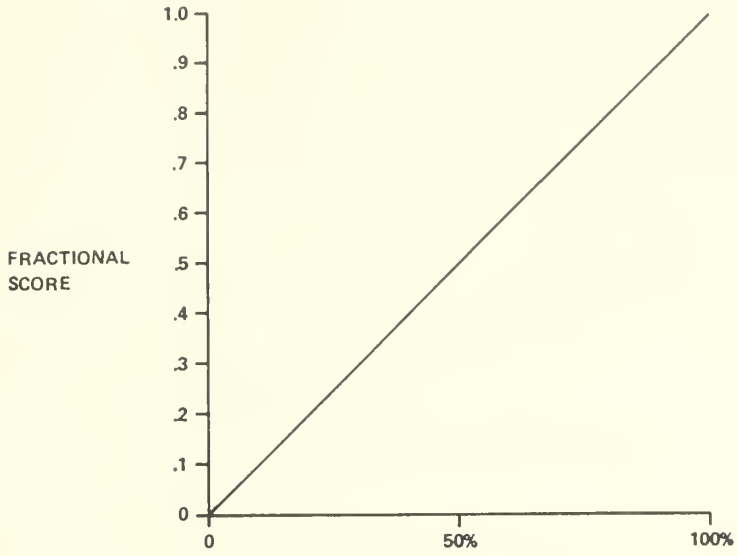

Figure 6.16 - Percent Leased for Exploration

The fractional score of this variable for sites is determined by a linear function. No lands leased receives a score of zero. Leasing on 100 percent of the land a maximum score of 1.0.

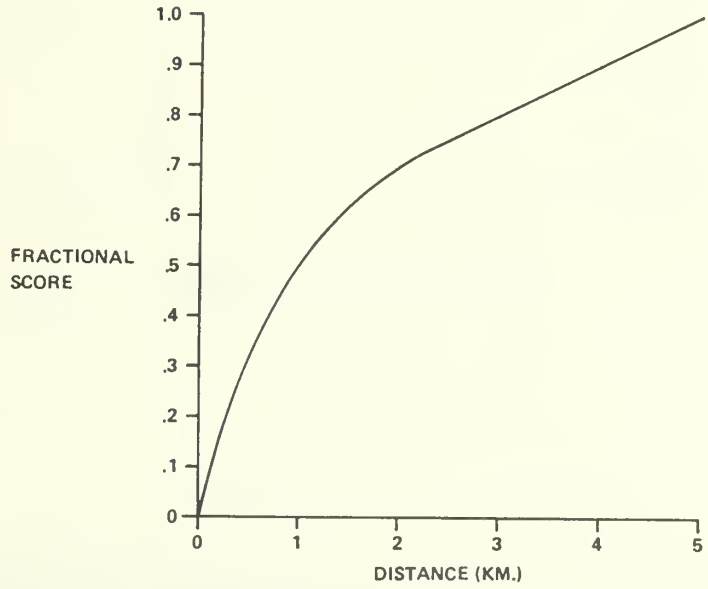

Figure 6.17 - Distance to Legally-Designated Areas

This curve is generally logarithmic in shape, with the distance axis beginning at zero, a distance of 5 kilometers receives full credit. generally, the closer the site is to a governmentally designated area, the more difficult the site will be to develop.

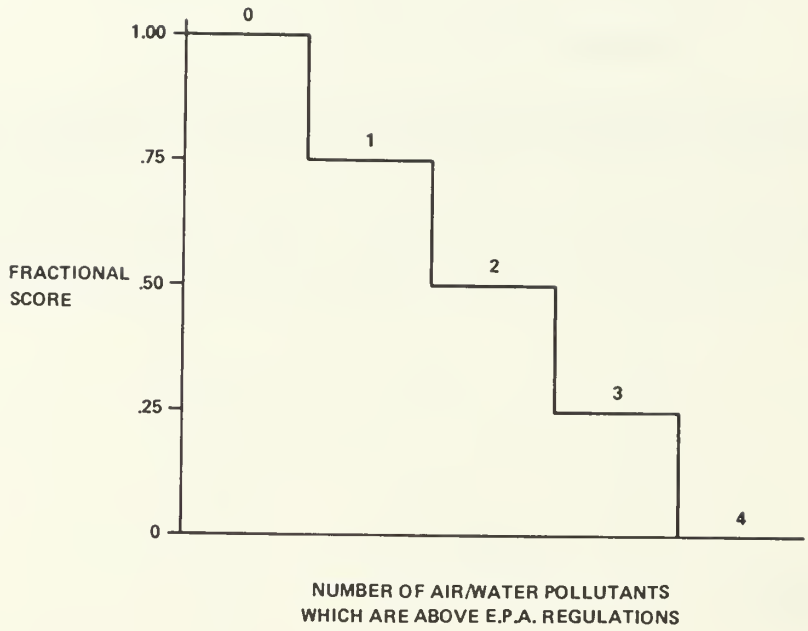

Figure 6.18 - Air/Water Concerns

The relation between a fractional score and the number of air/water pollutants above EPA regulations is a step function. No pollutants above established levels receives full credit. One, two, and three concerns receive a 0.75, 0.50, and 0.25 points, respectively, and four or more pollutants which exceed EPA standards receive zero points.

DIRECT UTILIZATION GRAPHS

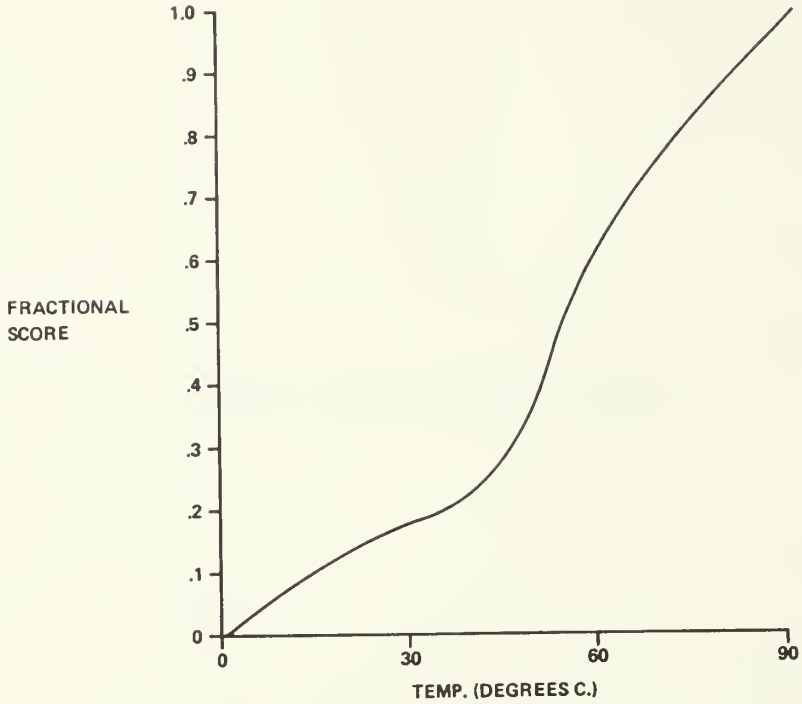

Figure 6.19 - Known Temperature of Fluids

This curve reflects the switch from heat pump technology to the more efficient direct utilization at approximately 50°C as recommended by Bechtel.

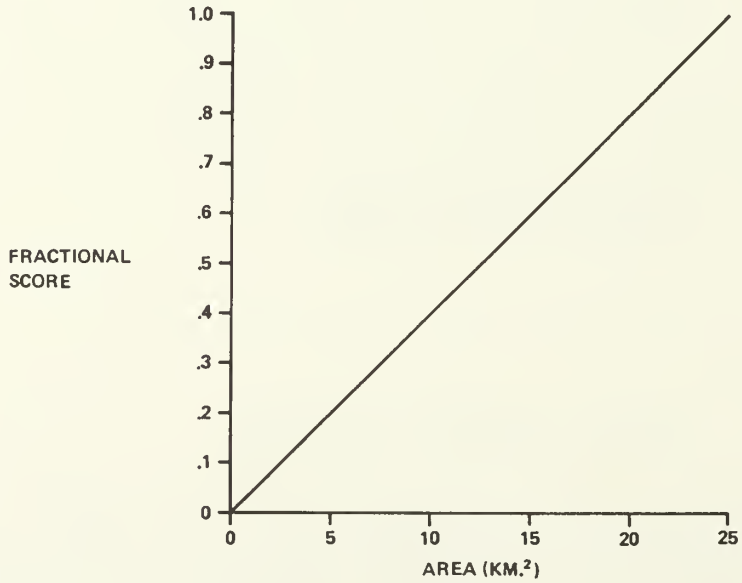

Figure 6.20 - Prospect Areal Extent

The fractional score for areal extent is related by a positive linear function. Simply, the greater the prospect area, the higher the fractional score. In this case, the surficial area is used as an indicator for probable reservoir size.

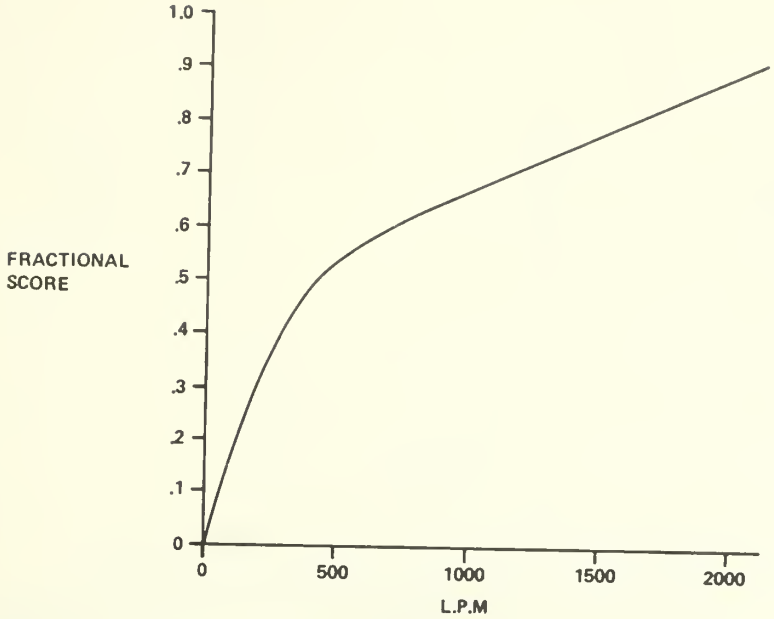

Figure 6.21 - Total Flow Rate

The time related energy capacity of a geothermal resource is related to flow rate. Therefore, fractional scores for total flow rate increase rapidly until a value of .4 at approximately 240 l.p.m. The curve then becomes nearly linear increasing from a score of 0.6 at 600 l.p.m. to a score of 1.0 at a flow rate of 1,980 l.p.m.

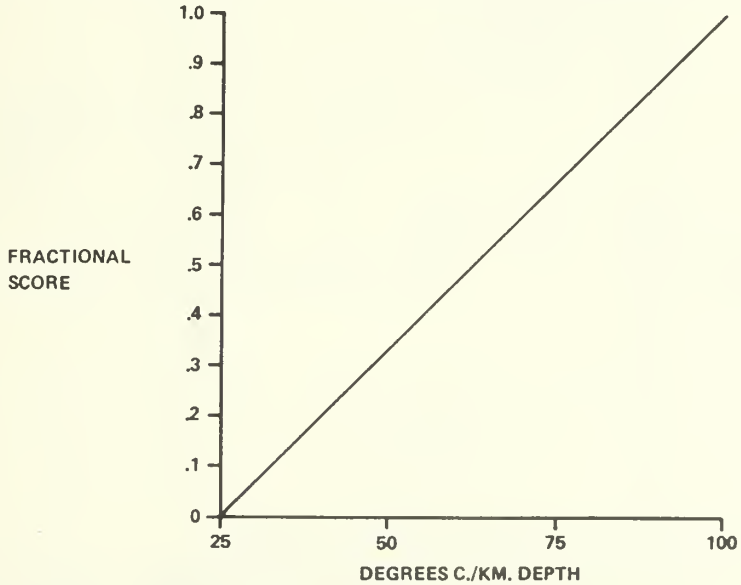

Figure 6.22 - Local Gradient

The fractional score is linearly related to the gradient. Twenty-five degrees Centigrade/km receives a minimum score of zero. One-hundred degrees Centigrade/km receives 1.0, the maximum score. Gradient parameters were set in a similar fashion to heat flow, above normal levels for low score and high gradient for the region receives a high score.

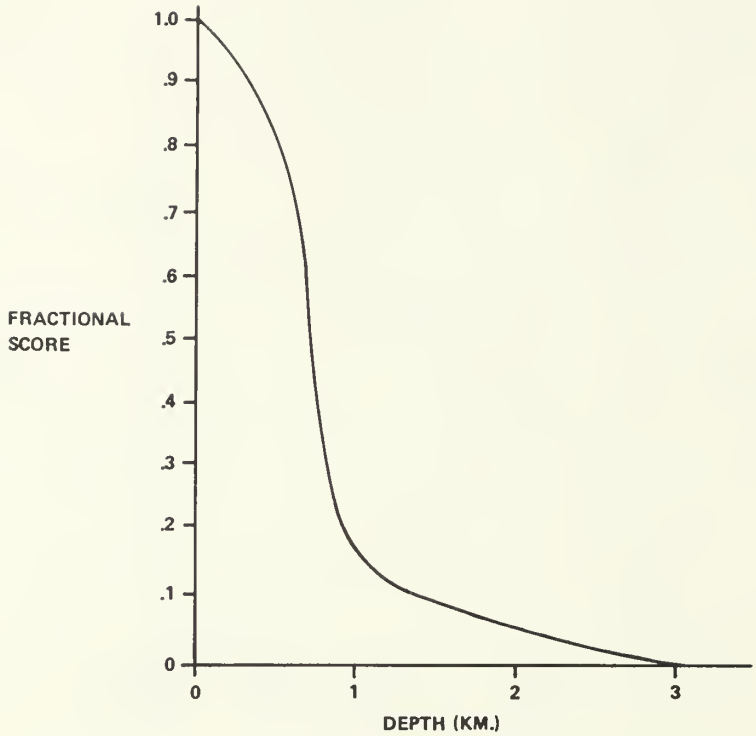

Figure 6.23 - Estimated Drilling Depth

The fractional scores drop off rapidly to less than .2 at a depth of about 1 kilometer. The curve then slowly descends until a fractional score of zero is reached at a depth of 3 kilometers. However, drilling expenses can be sustained in low temperature projects and still result in a profitable enterprise.

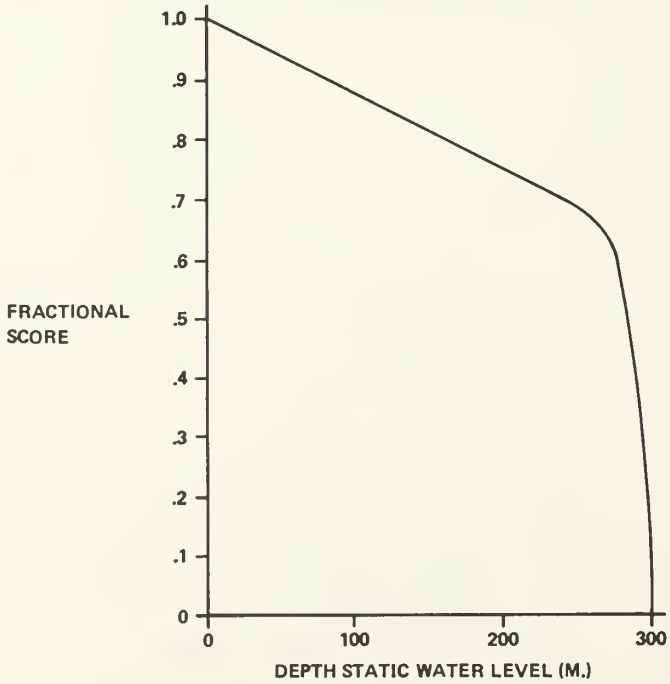

Figure 6.24 - Estimated Pumping Depth

Pumping costs are significant in low temperature applications. Very low static levels may ruin project economics. This function drops off linearly from a maximum score at a depth of zero to a score of approximately .65 at 260 meters. The curve then drops rapidly to a score of zero at about 300 meters, which is a maximum depth from which resources can be economically extracted.

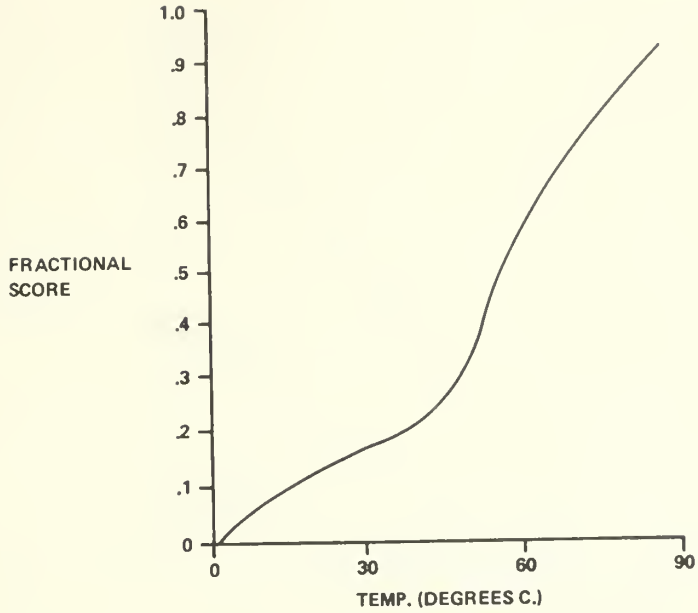

Figure 6.25 - Preferred Geothermometer Temperature

This curve reflects the switch from heat pump technology to the more efficient direct use at approximately 50°C as recommended by Bechtel.

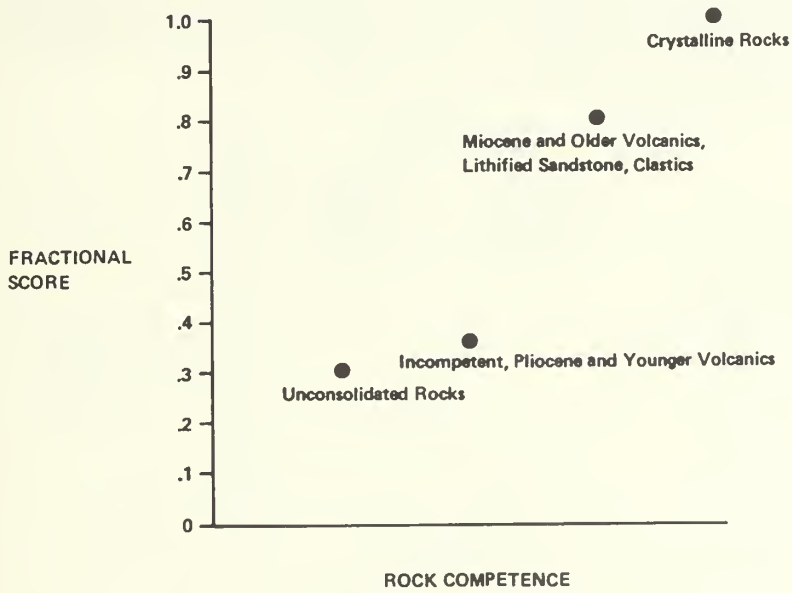

Figure 6.26 - Drilling Difficulty

This variable has four possible fractional scores as listed below:

> Crystalline Rocks (1.00); Miocene and Older Volcanics, Lithified Sandstone and Clastics (.8); Pliocene and Young Volcanic, Incompetent Rocks (.35); Unconsolidated Rocks (.3).

The rationale here is that more competent rocks, although slower to drill through, represent a more certain drilling environment. Voids, and loss of control are significant problems in young volcanic deposits and unconsolidated rock types.

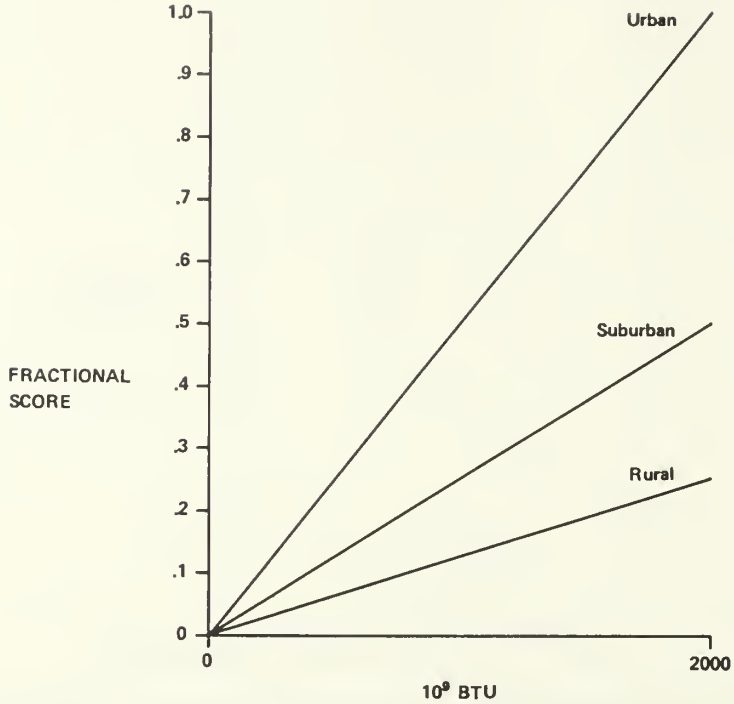

Figure 6.27 - Annual Heating Load/Density

This graph is a composite of three linearly increasing functions representing the rural, suburban, and urban heating load density. The expected annual heating load ranges are zero to 2,000 x 10^9 Btu. Rural, suburban, and urban functions yield scores from 0 to .25, .50 and 1.0, respectively, for the maximum heating load.

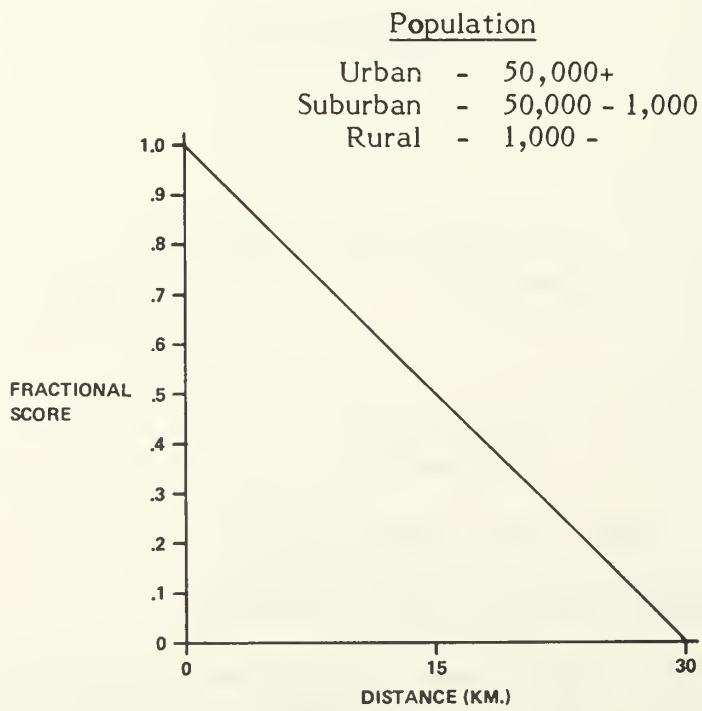

Figure 6.28 - Distance to Heating Load

Project costs for heat distribution are strongly affected by the distance between the heating load to the geothermal resources. The HEATPLAN program (Eliot Allen, 1984) was used to develop this relationship. Thirty kilometers was judged to be the maximum distance over which low temperature geothermal heat might be economically transported to a high load/high density market.

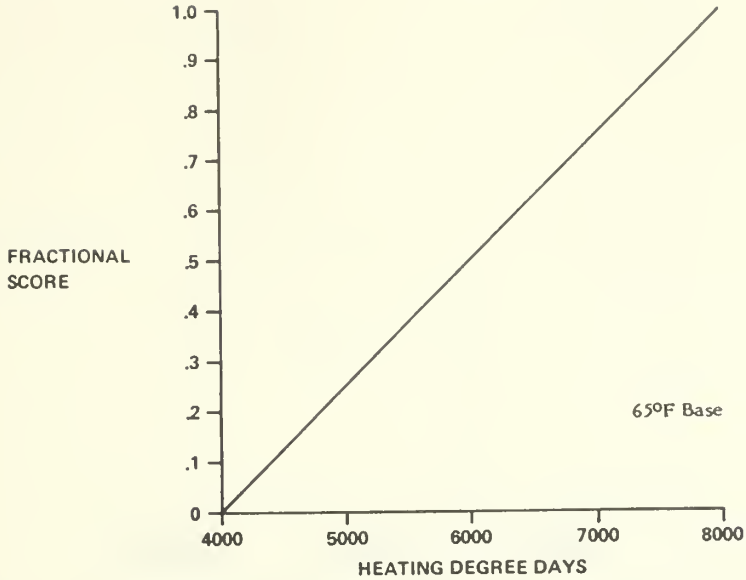

Figure 6.29 - Heating Degree Days

Areas with greater heating needs will have a greater seasonal utilization factor which makes the economics of substituting geothermal look more attractive. The fractional score is determined by a positive linear function. Four-thousand (4,000) heating degree days receive a minimum scores. Eight-thousand (8,000) heating degree days receive a maximum fractional score of 1.0

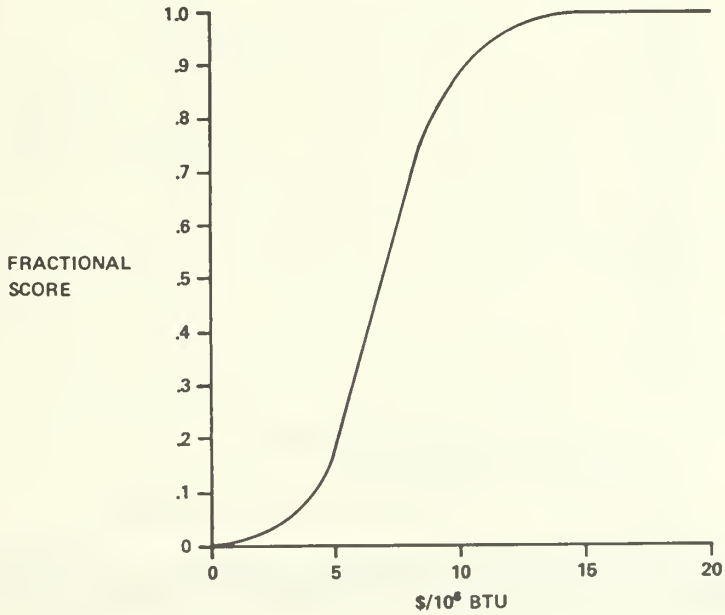

Figure 6.30 - Least Cost Heat Energy

The fractional score is related to cost of heat energy by an S curve which becomes asymptotic beyond the value of $\$10/10^6$Btu. It is assumed that conventional fuels costs will be about $10 per million Btus and that its cost competitiveness against other fuels drops off rapidly below that point. Fossil fuels are assumed to have a heat conversion efficiency of 70 percent.

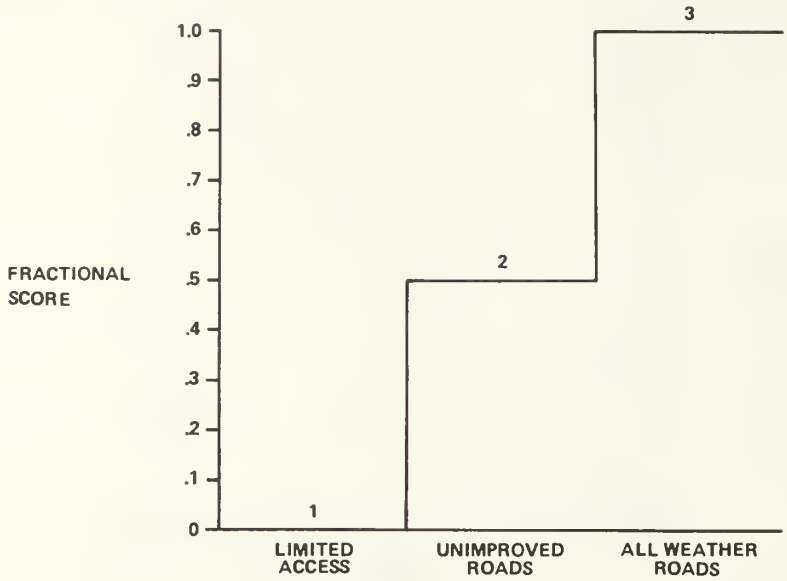

Figure 6.31 - Resource Site Accessibility

Site accessibility depends on road conditions. Improved roads receive a score of 1.0. Unimproved roads receive a score of 0.5. A site with no road access receives a zero score.

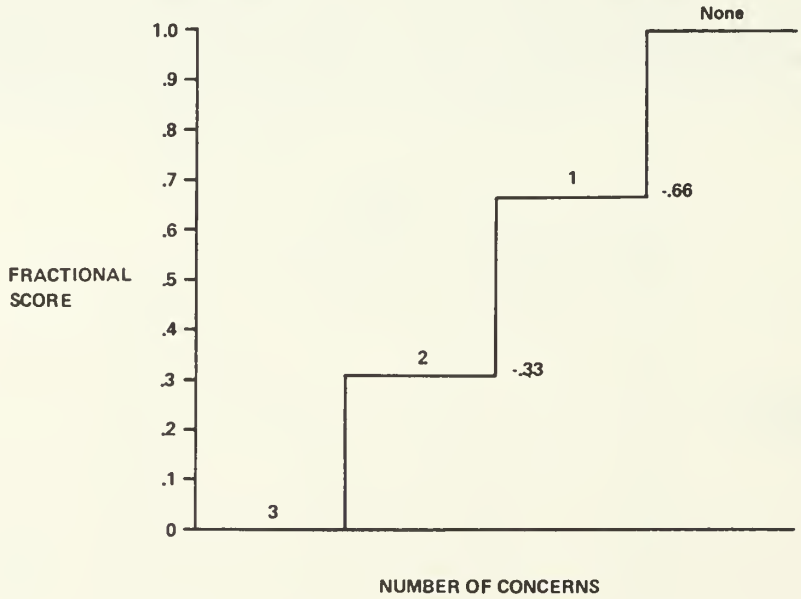

Figure 6.32 - Terrain of Pipeline Corridor

The fractional score for the terrain of pipeline corridor is described in this graph through a simple step function. The number of terrain-related concerns is used to produce the fractional score.

Areas of Concern

1. Terrain: Slope Greater Than 30%
2. Limited Access
3. Federal Lands
4. Agricultural Lands
5. Rivers/Wet Lands
6. Recreational Lands

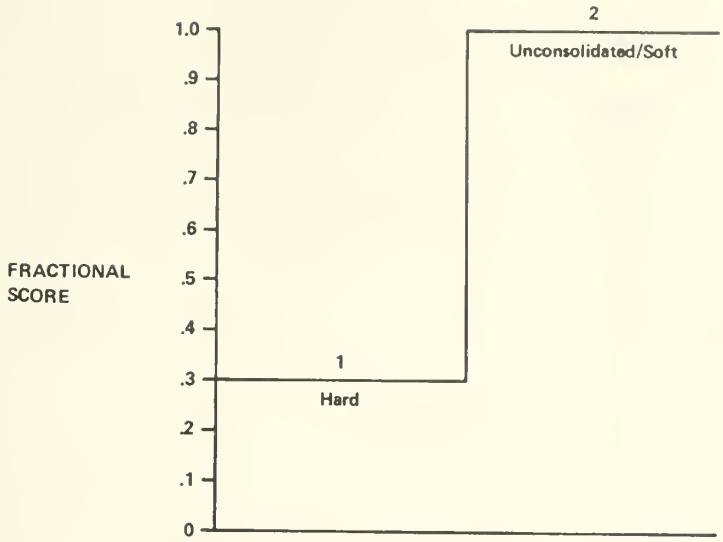

Figure 6.33 - Trenchability of Pipeline Corridor

The fractional score is categorized into two groups on the basis of surface rock type. Hard and soft materials receive, respectively, 0.3, and 1.0 for fractional scores.

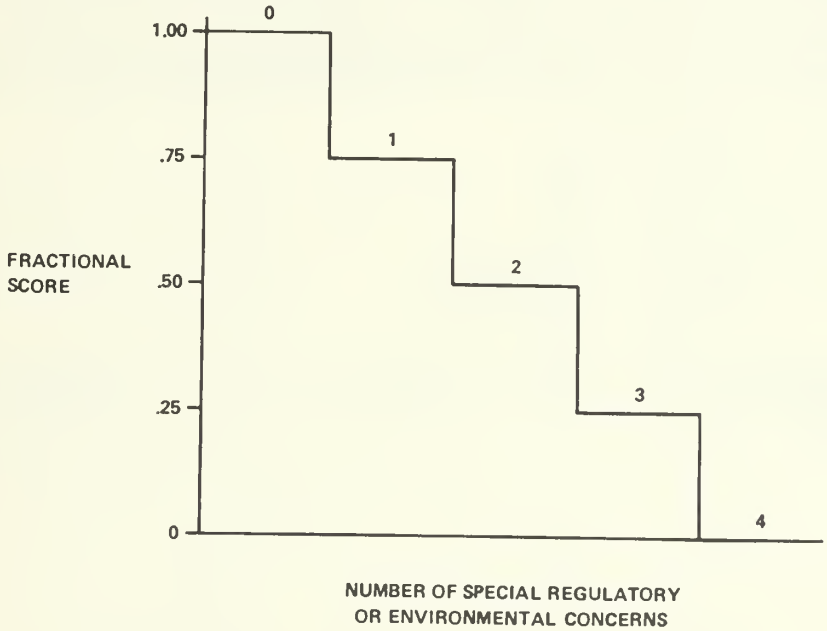

Figure 6.34 - Special Regulatory/Environmental Concerns

The relation between fractional score and number of special regulations or environmental concerns is given by a step function. No special concerns receives a maximum score. One concern receives 0.75 points. Two or three concerns receive fractional scores of 0.5 and 0.25, respectively, and four concerns receive one.

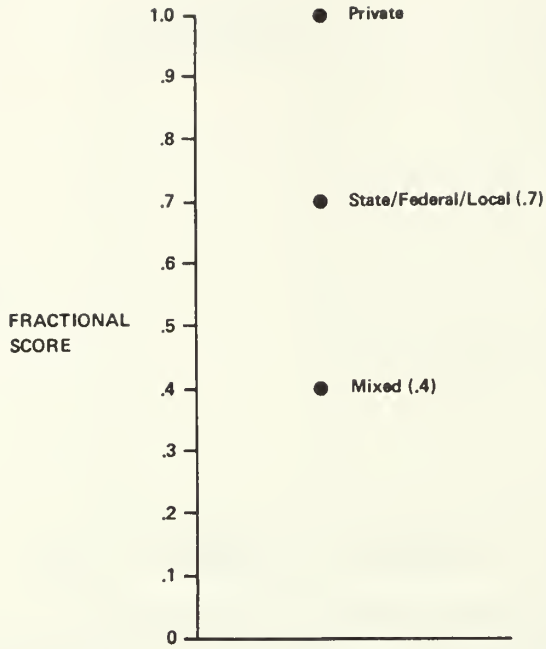

Figure 6.35 - Land/Resource Management

This variable assigns a value of 0.4, 0.7 and 1.0 to mixed; single government ownership, state/federal/local; and privately-owned lands, respectively. The reasoning is that private ownership presents the fewest problems to geothermal development, while mixed ownership/management presents the greatest time delays and associated difficulties.

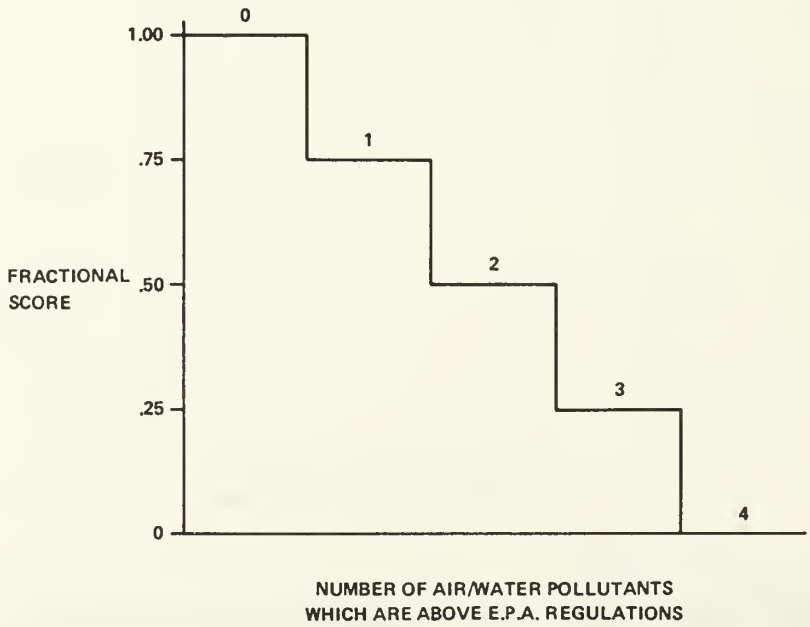

Figure 6.36 - Air/Water Concerns

The relation between a fractional score and the number of air/water pollutants above EPA regulations is a step function. No pollutants above established levels receives full credit. One, two, and three concerns receive a 0.75, 0.50, and 0.25 points, respectively, and four or more pollutants which exceed EPA standards receive zero points.

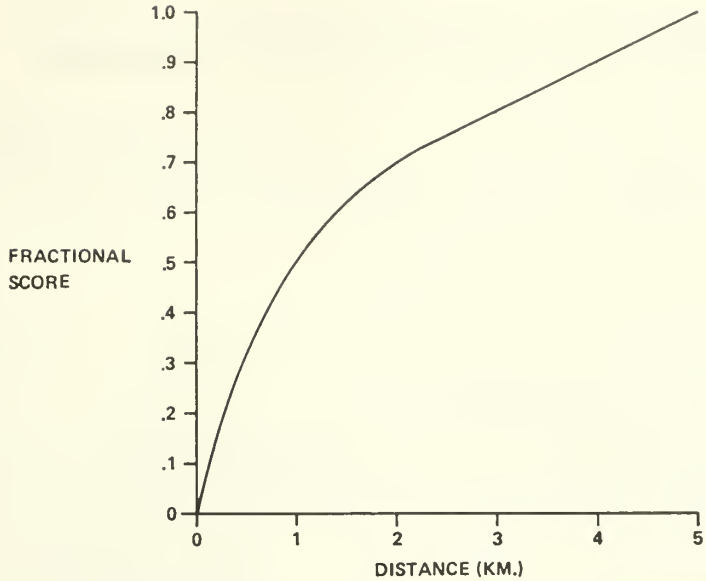

Figure 6.37 - Distance to Legally-Designated Areas

The closer a site is to a legally-designated area, the more difficult the site will be to develop. This curve expresses this relationship. When the distance axis begins at zero, a distance of 5 kilometers receives full credit.

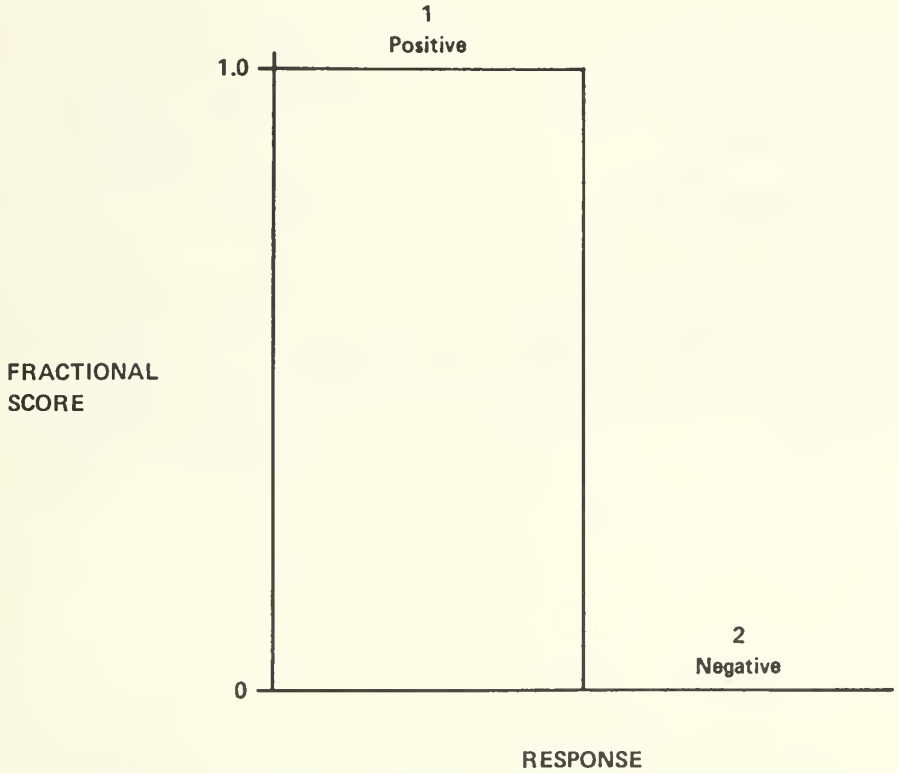

Figure 6.38 - Owner Attitude Toward Development

The relationship is a simple step function. A positive attitude of the owner receives a score of 1.0. A negative attitude toward development receives a score of zero.

Figure 6.39 - High Temperature Resource Ranking Data

Site: RAFT RIVER
Location: Cassia County, Idaho

		Estimate		Certainty Level
I.	Resource			
1.	Estimated Reservoir Temperature	147	C^o	1
2.	Estimated Drilling Depth	1,700	m	.9
3.	Age and Type of Volcanism	9	1,2..,9	.7
4.	Potential for High Permeability	3	1,2,3	.9
5.	Drilling Difficulty	3	1,2,3,4	.9
6.	Prospect Area Extent	16.7	km^2	.9
7.	Heat Flow	130	mW/m^2	.9
II.	Market			
8.	Terrain of Powerline Corridor	0	0,1,2,3	
9.	Resource Site Accessibility	2	1,2,3	
10.	Terrain of Development Site	1	1,2	
11.	Distance to Powerlines	0	km	
12.	Distance to Heating Load	19	km	
13.	Annual Heating Load	9.4	10^9Btu	
14.	Heat Load Density	3	1,2,3	
III.	Regulatory/Environmental			
15.	Land/Resource Management	3	1,2,3	
16.	Percent Leased for Exploration	0	%	
17.	Special Regulatory/Environmental Concerns	1	0,1,2,3,4	
18.	Distance to Legally Designated Areas	0	km	
19.	Air/Water Pollutants	2	0-4+	

Figure 6.40 - Direct Utilization Resource Ranking Data

Site: KLAMATH FALLS AREA
Location: Klamath Falls, Klamath County, Oregon

		Estimate		Certainty Level 0-1
I.	Resource			
1.	Known Temperature of Fluids	130	C°	.9
2.	Estimated Drilling Depth	.15	km	.9
3.	Preferred Geothermometer Temperature	60	C°	.3
4.	Total Flow Rate	45	L/sec.	.8
5.	Drilling Difficulty	1	1,2,3, or 4	.9
6.	Prospect Area Extent	32	km^2	.6
7.	Local Gradient	150	C°/km	.9
8.	Pumping Depth	50	m	.9
II.	Market			
9.	Distance to Heating Load	0	km	
10.	Resource Site Accessibility	3	1,2,3	
11.	Trenchability of Pipeline Corridor	2	1,2	
12.	Terrain of Pipeline Corridor	0	0,1,2,3	
13.	Annual Heating Load	655	10^9 Btu	
14.	Heat Load Density	1	1,2,3	
15.	Least Cost Heat Energy PP:L	9.99	$/$10^6$ Btu	
16.	Heating Degree Days	6,515	65°F Base	
III.	Regulatory/Environmental			
17.	Land/Resource Management	3	1,2,3	
18.	Special Regulatory/Environmental Concerns	1	0,1,2,3,4	
19.	Distance to Legally Designated Areas	5	km N/A	
20.	Air/Water Pollutants	0	0-4+	
21.	Owner Attitude Toward Development	1	1,2	

Figure 6.41 - High Temperature Resource Ranking Data

Site: RAFT RIVER
Location: Cassia County, Idaho

	Characteristic	Points	UC^2
I.	Resource		
1.	Estimated Reservoir Temperature	10.12	00.00
2.	Drilling Depth	7.17	0.51
3.	Age and Type of Volcanism	3.00	0.81
4.	Potential for High Permeability	14.00	1.96
5.	Drilling Difficulty	3.20	0.10
6.	Prospect Area Extent	2.67	0.07
7.	Heat Flow	4.00	0.16
	Subtotal	44.16	
II.	Market		
8.	Terrain of Powerline Corridor	6.00	
9.	Resource Site Accessibility	2.00	
10.	Terrain of Development Site	4.00	
11.	Distance to Powerlines	10.00	
12.	Distance to Heating Load	1.10	
13.	Annual Heating Load	8.52	
	Subtotal	31.52	
III.	Regulatory/Environmental		
14.	Land/Resource Management	8.00	
15.	Percent Leased for Exploration	0.00	
16.	Special Regulatory/Environmental Concerns	12.00	
17.	Distance to Legally Designated Areas	0.07	
18.	Air/Water Pollutants	2.50	
	Subtotal	22.57	
	TOTAL	89.83	3.62

SORT UC^2 = 1.9

Most Likely Score	89.83
Probable Uncertainty	1.90
Likely Minimum Score	87.93
Normalized Minimum Score	.676

Figure 6.41 - High Temperature Resource Ranking Data
(Continued)

Site: RAFT RIVER
Location: Cassia County, Idaho

		Estimate		Certainty Level
I.	Resource			
1.	Estimated Reservoir Temperature	147	C°	1
2.	Estimated Drilling Depth	1,700	m	.9
3.	Age and Type of Volcanism	9.00		.7
4.	Potential for High Permeability	3.00		.9
5.	Drilling Difficulty	3.00		.9
6.	Prospect Area Extent	16.70	km^2	.9
7.	Heat Flow	130	MW/m^2	.9
II.	Market			
8.	Terrain of Powerline Corridor	00.00		
9.	Resource Site Accessibility	2.00		
10.	Terrain of Development Site	1.00		
11.	Distance to Powerlines	00.00	km	
12.	Distance to Heating Load	19.00	km	
13.	Annual Heating Load	9.40	10^9 Btu	
III.	Regulatory/Environmental			
14.	Land/Resource Management	3.00		
15.	Percent Leased for Exploration	00.00	%	
16.	Special Regulatory/Environmental Concerns	1.00		
17.	Distance to Legally Designated Areas	00.00	km	
18.	Air/Water Pollutants	2.00		

Figure 6.42 - Direct Utilization Resource Ranking Data

Site: KLAMATH FALLS
Location: Klamath County, Oregon

	Characteristic	Points	UC^2
I.	Resource		
1.	Fluids - Temperature	11.00	1.21
2.	Drilling Depth	7.00	0.49
3.	Geothermal Temperature	2.29	2.57
4.	Flow Rate	7.00	1.96
5.	Drilling Difficulty	0.55	8.02
6.	Prospect Area Extent	8.00	10.24
7.	Local Gradient	6.00	0.36
8.	Pumping Depth	4.74	0.22
	Subtotal	46.58	
II.	Market		
9.	Heat Load Distance	8.00	
10.	Resource Site Accessibility	2.00	
11.	Trenchability	2.00	
12.	Terrain of Development Site	2.00	
13.	Annual Heating Load	7.21	
14.	Least Energy	7.48	
15.	Heating Degree Days	3.77	
	Subtotal	32.46	
III.	Regulatory/Environmental		
16.	Land/Resource Management	7.00	
17.	Special Regulatory/Environmental Concerns	9.00	
18.	Distance to Legally Designated Areas	2.96	
19.	Air/Water Pollutants	5.00	
20.	Owner Attitude	3.00	
	Subtotal	26.96	
	TOTAL	105.99	17.05

SORT UC^2 = 4.13

Most Likely Score	105.99
Probable Uncertainty	4.13
Likely Minimum Score	101.86
Normalized Minimum Score	.784

Figure 6.42 - High Temperature Resource Ranking Data
(Continued)

Site: KLAMATH FALLS
Location: Klamath County, Oregon

		Estimate		Certainty Level
I.	Resource			
1.	Estimated Reservoir Temperature	130	C°	.9
2.	Estimated Drilling Depth	0.15	km	.9
3.	Geothermal Temperature	60.00		.3
4.	Flow Rate	45.00	L/sec.	.8
5.	Drilling Difficulty	1.00		.9
6.	Prospect Area Extent	32	km^2	.6
7.	Local Gradient	150	C/km	.9
8.	Pumping Depth	50	m	.9
II.	Market			
9.	Load Distance	00.00	km	
10.	Resource Site Accessibility	3.00		
11.	Trenchability	2.00		
12.	Terrain of Development Site	00.00		
13.	Annual Heating Load Density	655	10^9 Btu	
14.	Least Energy	9.99	$\$/10^6$ Btu	
15.	Heating Degree Days	6,515	65°F Base	
III.	Regulatory/Environmental			
16.	Land/Resource Management	3.00		
17.	Special Regulatory/Environmental Concerns	1.00		
18.	Distance to Legally Designated Areas	5.00	km	
19.	Air/Water Pollutants	00.00		
20.	Owner Attitude	1.00		

CHAPTER 7

Exploration Phases

7.0 EXPLORATION PHASES

7.1 Introduction

At least a minimal amount of surface exploration has been completed on most of the geothermal sites studied in this report. Knowledge of the stage of exploration at any particular site is useful both to evaluate the quality of the resource estimate and to estimate exploration costs that will accrue in the course of development at the site.

This chapter is divided into two sections. The first describes the exploration activities that can be expected to occur at a "standard" geothermal site. These activities will vary slightly according to whether it is a high or direct utilization site. The second section contains estimates of the costs associated with each of the various exploration steps. These costs vary depending on site location (i.e., Cascades as opposed to Basin and Range sites) and resource temperature (i.e., high or low temperature sites).

7.2 Phase of Exploration

Exploration at any given geothermal site will normally proceed through a series of phases. Tables 7.1 and 7.2 show the status of the exploration process at potential high temperature sites in the states of Oregon and Washington, while Tables 7.3-7.6 show the status of exploration at binary wellhead sites in Idaho, Montana, Oregon, and Washington, respectively. Tables 7.7-7.10 show the status of exploration for direct utilization sites in the same four states.

In general, the exploration process for high temperature resources will proceed through four phases: Phase I includes literature searches, regional spring sampling and heat flow studies, reconnaissance mapping, and regional geophysics. Much of the Phase I work has been completed for the high temperature sites in the four-state region. Phase II consists of site specific heat flow studies (including shallow temperature gradient drilling), water and soil chemistry, geologic mapping, and geophysics. A considerable amount of Phase II work has been completed at many sites, but exploration at most sites is not far advanced. Phase III includes hydrologic modeling and intermediate depth drilling to further define and confirm the thermal anomaly identified in Phase II. Very little Phase III work has been completed in the Northwest. Phase IV consists of deep drilling, reservoir testing and evaluation, and quantitative estimates of the reservoir.

Only Raft River, Idaho, has progressed to Phase IV. A considerable amount of Phase IV type work has been completed at Klamath Falls, Oregon, but most of it has been used to evaluate the shallow, lower temperature direct utilization resource. The nature of deep, potentially high temperature resources in the Klamath Falls area have not yet been investigated.

The phases of exploration for direct utilization resources are similar to those for high temperature resources, except that three instead of four phases are involved. Phase I consists of a literature search, widely spaced temperature gradient and spring sampling surveys, reconnaissance mapping, and limited regional geophysics. Phase II consists of more detailed heat flow and spring sampling studies, geologic mapping, and limited geophysics. Phase III involves deep drilling to test the aquifer, reservoir testing and evaluation, and quantitative reservoir estimation. There is no intermediate depth drilling phase as there is in high temperature exploration.

It is assumed in this report that resources with estimated reservoir temperatures in the range of 90-149°C (194-300) will utilize binary wellhead electrical conversion technologies. A lower rate of return at these sites will not justify the more detailed exploration carried out at most sites with central plant electrical generation potential. Therefore, it is assumed that intermediate temperature sites (90-149°C) will undergo an exploration process more similar to direct utilization sites than electrical generation sites (Tables 7.3-7.6).

It is not expected that all of the exploration steps listed in Tables 7.1-7.10 will be completed at each and every site, or that exploration will necessarily proceed in the ordered fashion indicated in the tables. The tables only indicate the relative amount of assessment work that has been completed at each of the prospective sites in the four-state area and gives an indication of what can be expected to be completed before development occurs.

7.3 Costs of Exploration.

An estimation of the cost of completing the exploration process is necessary to calculate the cost of energy production at a specific site. These costs, for example, are required input into HEATPLAN, the program used in this report to evaluate the economics of direct utilization resources. Tables 7.11 and 7.12 list the costs, respectively, for each of the exploration steps for high and direct utilization sites. These costs are derived from a variety of sources, including: (1) the experience of the Oregon Department of Geology and Mineral Industries (DOGAMI) for costs of literature searches, regional and local heat flow, spring sampling, and soil sampling surveys, geologic mapping, and shallow temperature gradient drilling, (2) Senti (1983) for geophysical costs, and (3) industry expertise for other costs.

The following is a list of assumptions used to derive the cost estimates of Tables 7.11 and 7.12. Included is the source of the information used to make the estimate.

Cost Assumptions:

7.3.1 High Temperature Resources

Phase I

I.1 Two weeks of geologist time --- DOGAMI.

I.2 Six weeks of geologist time with per diem and vehicle costs (Vehicle costs based on Oregon State Motor Pool costs, per diem based on State of Oregon rates) --- DOGAMI.

I.3 Six weeks of geologist time with per diem and vehicle costs; 25 spring samples @ $62.50/sample (1984 University of Utah Research Institute (UURI) prices) --- DOGAMI.

I.4 Six weeks of geologist time with per diem and vehicle costs; 5 K-Ar dates @ $400/date; 20 whole rock analyses @ $40/analysis; and $1000 for air photos, maps, etc. --- DOGAMI.

I.5a Analysis by a consultant of data collected in Phase I.2 --- D. Blackwell, Southern Methodist University, personal communication.

I.5b Assumes 300 gravity stations @ $120/station -- S. Pitts, Northwest Geophysical Associates, personal communication.

I.5c Assumes 772 line kilometers of aeromagnetics @ $12.42/line kilometer --- S. Pitts, Northwest Geophysical Associates, personal communication.

I.5d Assumes "regional" area of 1,036 km^2 and 1 magnetotelluric station per 39 km^2 @ $3,000/station --- Senti (1983) and S. Pitts, Northwest Geophysical Associates, personal communication.

I.5e Assumes that, due to the high cost of the method, no "regional" seismic work would be scheduled for exploration (though existing data would be utilized) --- S. Pitts, Northwest Geophysical Associates, personal communication.

Phase II

II.1 Three weeks of geologist time with per diem and vehicle costs --- DOGAMI.

II.2a Seven weeks of geologist time with per diem and vehicle costs plus the analysis of 25 fluid samples @ $62.50/sample (UURI) --- DOGAMI.

II.2b Assumes mercury soil sampling; $5,000 cost of instrument plus 2.5 months operator time to collect and analyze and prepare reports (includes per diem and vehicle costs) --- DOGAMI and J. LaFleur, California Energy Company, personal communication.

II.2c Assumes radon sampling; 1 sample/km^2 over 55 km^2 area @ $18/sample --- P. Brophy, California Energy Company, personal communication.

II.2d Analysis of 25 samples @ $62.50/sample --- UURI and DOGAMI.

II.3 Consultant; $750/day for 12 days --- L. Capuano, Thermasource, Inc., personal communication.

II.4 Assumes production of one 7.5' quadrangle. Four field months (plus per diem and vehicle expenses) and four office months for a Cascades map and three office and three field months for a Basin and Range map. Includes 3 K-Ar dates @ $400/date, 20 whole rock analyses @ $40/analysis, 100 thin sections @ $4/section, and $500 for maps, air photos, etc. --- DOGAMI.

II.5 $2,500 for one 7.5' quadrangle; includes investigation, drafting, and strain analysis; no field check --- C. Kienle, Dames and Moore, personal communication.

II.6 Assumes a thermal anomaly of approximately 5 mi^2. In the Cascades one 610 m hole/mi^2 @ $230,000/hole plus some "slack" to allow for an additional hole or drilling problems. In the Basin and Range assumes a program of thirty 152 m. temperature gradient holes @ $5,000/hole ---A. Waibel, Columbia Geoscience, personal communication; J. LaFleur and Paul Brophy, California Energy Company, personal communication; DOGAMI.

II.7a Consultant providing detailed heat flow analysis of all temperature gradient holes; includes thermal conductivity determinations --- D. Blackwell, Southern Methodist University, personal communication.

	II.7b	Profiles with .4 km data spacing; 100 stations @ $100/station --- S. Pitts, Northwest Geophysical Associates, personal communication.
	II.7c	Done in conjunction with site specific gravity study; adds $45/station to gravity station cost --- S. Pitts, Northwest Geophysical Associates, personal communication.
	II.7d	Assumes a site of 55 km^2 on the flanks of Newberry Volcano; one magnetotelluric station per 8 km^2 @ $3,000/station plus 32 line kilometers of surface resistivity for 8-10 km^2 of most promising area @ $950/line kilometer --- Senti (1983) and P. Brophy, California Energy Company, personal communication.
	II.7e	Assumes no seismic work completed in Cascades due to limited usefulness in volcanic terrain; reflection survey for 13 km^2 area is approximately 8 times more expensive than refraction survey which requires 405 stations @ $120/station --- Senti (1983) and Duprat and Omnes (1976).
Phase III	III.1	No "intermediate" depth drilling in Cascades as 610 m holes were drilled in Phase II.6; in Basin and Range assumes five 610 m holes @ $230,000/hole --- P. Brophy and J. LaFleur, California Energy Company, personal communication.
	III.2	Consultant @ $1,000/day for 30 days --- L. Capuano, Thermasource, Inc., personal communication.
Phase IV	IV.1	Two 1,830 m wells @ $500,000/well --- P. Brophy and J. LaFleur, California Energy Company, personal communication.

IV.2 Equipment, 30 days @ $3,000/day; downhole fluid sampling, 10 samples @ $1,000/sample; downhole geophysical surveys, 8 surveys @ $5,000/survey; reports, 4 wells @ 5,000/well ---L. Capuano, Thermasource, Inc., personal communication.

IV.3 Consultant, $750/day for 10 days --- L. Capuano, Thermasource, Inc., personal communication.

7.3.2 Direct Utilization Resources

Phase I

I.1 Two weeks of geologist time -- DOGAMI.

I.2 Six weeks of geologist time with per diem and vehicle costs (vehicle costs based on Oregon State Motor Pool costs, per diem based on State of Oregon rates) -- DOGAMI

I.3 Six weeks of geologist time with per diem and vehicle costs; 25 spring samples @ $62.50/sample (1984 University of Utah Research Institute (UURI) prices) -- DOGAMI.

I.4 Six weeks of geologist time with per diem and vehicle costs; 5 K-Ar dates @ $400/date; 20 whole rock analyses @ $40/analysis; and $1,000 for air photos, maps, etc. -- DOGAMI.

I.5a Analysis by a consultant of data collected in Phase 1.2 -- D. Blackwell, Southern Methodist University, personal communication.

I.5b Assumes 300 gravity stations @ $120/station -- S. Pitts, Northwest Geophysical Associates, personal communication.

Phase II

II.1 Three weeks of geologist time with per diem and vehicle costs -- DOGAMI.

II.2a Seven weeks of geologist time with per diem and vehicle costs plus the analysis of 25 fluid samples @ $62.50/sample (UURI) --DOGAMI.

II.2b Assumes mercury soil sampling; $5,000 cost of instrument plus 2.5 months operator time to collect and analyze and prepare reports (includes per diem and vehicle costs) -- DOGAMI and J. LaFleur, California Energy Company, personal communication.

II.2c Assumes radon sampling; approximately 1 sample/km^2 over 55 km^2 area @ $16/sample -- P. Brophy, California Energy Company, personal communication.

II.2d Analysis of 25 samples @ $62.50/sample -- UURI and DOGAMI.

II.3 Consultant; $750/day for 12 days -- L. Capuano, Thermasource, Inc., personal communication.

II.4 Assumes production of one 7.5 ft. quadrangle. Four field months (plus per diem and vehicle expenses) and four office months for a Cascades map and three office and three field months for a Basin and Range map. Includes 3 K-Ar dates @ $400/date, 20 whole rock analyses @ $40/analysis, 100 thin sections @ $4/section, and $500 for maps, air photos, etc. --DOGAMI.

II.5 $2,500 for one 7.5 ft. quadrangle; includes investigation, drafting, and strain analysis; no field check -- C. Kienle, Dames and Moore, personal communication.

II.6a Consultant providing detailed heat flow analysis of all temperature gradient holes; includes thermal conductivity determinations -- D. Blackwell, Southern Methodist University, personal communication.

II.6b Twenty line miles of resistivity @ $950/line kilometer --- DOGAMI and Senti (1983).

II.6c Too expensive for use in a direct utilization resource area ---DOGAMI.

Phase III

III.1 One 914 m well @ $200,000/well --- DOGAMI and G. Bloomquist, Washington State Energy Office, personal communication.

III.2 Assumes 30 day pump test. One field month (plus per diem and vehicle costs) and six office months; equipment costs ($6,000); pump installation and removal ($800); pump rental ($2,000); electrical costs($200); fluid analyses, 10 samples ($625); and a spinner survey of the return well ($1000) ---DOGAMI and L. Forcella, Oregon Department of Water Resources, personal communication.

III.3 Consultant, $750/day for 5 days --- DOGAMI and L. Forcella, Oregon Department of Water Resources, personal communication.

ELECTRICAL GENERATION SITES
STATUS OF EXPLORATION
& ASSESSMENT

OCTOBER 1984

STATE: OREGON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	Magnetics	Electrical	Seismic	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of results:	Thermal Sampling	Soil Sampling	Gas Sampling	Cold Water Sampling	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Shallow Drilling of 500' Temperature gradient Wells to Define Heat Flow Anomolies	Detailed Geophysical Exploration:	Heat Flow	Gradients	Gravity	Magnetics	Electrical	Seismic	PHASE III—DIRECT EXPLORATION OF THERMAL ANOMALIES	Intermediate Depth Drilling of 2,000' Wells to Define Thermal Anomolies	Quantitative Hydrologic Modelling of the Geothermal System (Includes Geophysics)	PHASE IV—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 3,000' to 6,000' Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Bearwallow Buttes	97	X	X	X	X		X	X	X	X		N/A	0																			0			0			
Melvin/Three Creek Butte	97	X	X	X	X		X	X	X	X		N/A	28								X	X										0			0			
Newberry Volcano	100	X	X	X	X		X	X	X	X	X	X	32	X			X				X											0			0			
Alvord Hot Springs	100	X	X	X	X		X	X	X	X	X	N/A	14	X																		0			0			
Borax Lake	100	X	X	X	X		X	X	X	X	X	N/A	14	X																		0			0			
Trout Creek	91	X	X	X	X		X	X		X			0																			0			0			
Mt. McLoughlin	97	X	X	X	X		X	X	X	X		N/A	14										X									0			0			
Glass Butte	94	X	X	X	X		X	X		X		N/A	51	X			X				X			X								0			0			
Generic High Cascades	97	X	X	X	X		X	X	X	X		N/A	14										X									0			0			
Cappy-Burn Butte	97	X	X	X	X			X	X	X		N/A	14										X									0			0			
Crater Lake Area	97	X	X	X	X			X	X	X		N/A	28								X		X									0			0			
Klamath Falls	100	X	X	X	X		X	X	X	X	X	N/A	71				X			X	X	X	X	X		X					X	0			0			
Klamath Hills	100	X	X	X	X		X	X	X	X	X	N/A	37				X			X		X	X								X	0			0			
Olene Gap	100	X	X	X	X		X	X	X	X	X	N/A	34				X					X	X								X	0			0			
Neal HS	100	X	X	X	X		X	X	X	X	X	X	28									X	X									0			0			
Vale HS	100	X	X	X	X		X	X	X	X	X	X	72	X			X					X	X	X			X	X	X			0			0			

SEO 982

Table 7.1 — Phase of Exploration - Electrical Generation Sites - Oregon

ELECTRICAL GENERATION SITES
STATUS OF EXPLORATION
& ASSESSMENT

OCTOBER 1984

STATE: WASHINGTON

	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	Magnetics	Electrical	Seismic	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of results:	Thermal Sampling	Soil Sampling	Gas Sampling	Cold Water Sampling	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Shallow Drilling of 500 Temperature gradient Wells to Define Heat Flow Anomolies	Detailed Geophysical Exploration:	Heat Flow	Gradients	Gravity	Magnetics	Electrical	Seismic	PHASE III—DIRECT EXPLORATION OF THERMAL ANOMALIES	Intermediate Depth Drilling of 2,000 Wells to Define Thermal Anomolies	Quantitative Hydrologic Modelling of the Geothermal System (Includes Geophysics)	PHASE IV—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 3,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Mt. Baker	86	X	X	X	X				X	X			21	X		X		X													0			0			

SEO 982

Table 7.2 — Phase of Exploration - Electrical Generation Sites - Washington

BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: IDAHO	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Vulcan Hot Springs	80	X	X	X	X					26	X	X								0			
Carbarton Hot Springs	80	X	X	X	X					26	X	X								0			
Boiling Hot Springs	80	X	X	X	X					26	X	X								0			
Murphy Hot Springs	80	X	X	X	X					26	X	X								0			
Indian Creek Hot Springs	80	X	X	X	X					26	X	X								0			
Big Creek Hot Springs	80	X	X	X	X					26	X	X								0			
Owl Creek Hot Springs	80	X	X	X	X					26	X	X								0			
Sharkey Hot Springs	80	X	X	X	X					26	X	X								0			
Riggins Hot Springs	80	X	X	X	X					26	X	X								0			
White Arrow	93	X	X	X	X		X		X	26	X	X								0			
Roystone Hot Springs	86	X	X	X	X				X	26	X	X								0			
Squaw Creek Hot Springs	86	X	X	X	X				X	26	X	X								0			
Battle Creek Hot Springs	86	X	X	X	X				X	26	X	X								0			
Ben Meek Well	86	X	X	X	X				X	26	X	X								0			
Maple Grove Hot Springs	86	X	X	X	X				X	26	X	X								0			
Latty Hot Springs	86	X	X	X	X				X	26	X	X								0			
Sunbeam Hot Springs	80	X	X	X	X					26	X	X								0			
Raft River Area	100	X	X	X	X		X	X	X	100	X	X	X	X	X		X	X	X	100	X	X	X
Worswick Hot Springs	80	X	X	X	X					26	X	X								0			
Barron's Hot Springs	94	X	X	X	X		X	X		38	X	X		X						0			
Magic Hot Springs	94	X	X	X	X		X	X		50	X	X		X	X					0			
Bonneville Hot Springs	80	X	X	X	X					26	X	X								0			

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Table 7.3 — Phase of Exploration - Binary Wellhead Sites - Idaho

BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: IDAHO	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Deer Creek Hot Springs	86	X	X	X	X				X	26	X	X								0			
Krigbaum Hot Springs	86	X	X	X	X				X	26	X	X								0			
White Licks Hot Springs	86	X	X	X	X				X	26	X	X								0			
Cove Creek Hot Spring	87	X	X	X	X		X			13		X						X		0			
Crane Creek Hot Spring	87	X	X	X	X		X			13		X						X		0			
Guyer Hot Springs	86	X	X	X	X				X	50	X	X		X	X					0			
Big Southern Butte	60	X		X	X					0										0			
Island Park Caldera	80	X	X	X	X					25	X			X						0			
Rexburg Caldera	80	X	X	X	X					12				X						0			
Blackfoot Lava Field	60	X		X	X					0										0			

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BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: MONTANA	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 1,000' to 6,000' Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Ennis	87	X	X	X	X		X			51		X	X	X				X		0			
Silver Star	67	X		X	X		X			51		X	X	X				X		0			
Marysville Well	27	X					X			63		X	X	X			X	X		100	X	X	X
Gregson Hot Springs	27	X					X			38		X	X					X		0			
Jackson Hot Springs	27	X					X			26		X	X							0			
Boulder Hot Springs	27	X					X			26		X	X							0			
Broadwater Hot Springs	27	X					X			51		X	X	X				X		0			
Norris Hot Springs	27	X					X			26		X	X							0			

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Table 7.4 — Phase of Exploration - Binary Wellhead Sites - Montana

BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: OREGON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Kropp HS	96	X	X	X	X		X	X		0										0			
Austin HS	100	X	X	X	X		X	X	X	38	X	X			X					0			
Mt. Hood	100	X	X	X	X		X	X	X	62	X	X		X	X		X			0			
China Hat & East Butte	100	X	X	X	X		X	X	X	0										0			
Frederick Butte	96	X	X	X	X		X	X		0										0			
Quartz Mountain	100	X	X	X	X		X	X	X	0										0			
Shukash Basin	100	X	X	X	X		X	X	X	24				X	X					0			
Umpqua HS	100	X	X	X	X		X	X	X	12					X					0			
Blue Mountain HS	96	X	X	X	X		X	X		0										0			
Weberg HS	96	X	X	X	X		X	X		0										0			
Crane HS	100	X	X	X	X		X	X	X	0										0			
Diamond Craters	96	X	X	X	X		X	X		0										0			
O.J. Thomas Well	100	X	X	X	X		X	X	X	0										0			
Rustler Peak	100	X	X	X	X		X	X	X	12					X					0			
Barry Ranch HS	100	X	X	X	X		X	X	X	0										0			
Cougar Peak Area	96	X	X	X	X		X	X		0										0			
Devils Garden Area	96	X	X	X	X		X	X		0										0			
Fischer HS	100	X	X	X	X		X	X	X	49	X			X	X			X		0			
Four Craters Lava Field	96	X	X	X	X		X	X		0										0			
Hallinan Springs	100	X	X	X	X		X	X	X	0										0			
Lakeview	100	X	X	X	X		X	X	X	0										0			
Squaw Ridge Field	96	X	X	X	X		X	X		0										0			

Table 7.5 — Phase of Exploration - Binary Wellhead Sites - Oregon

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BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: OREGON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000' to 6,000' Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Summer Lake HS	96	X	X	X	X		X	X		0										0			
Belknap	100	X	X	X	X		X	X	X	50	X	X		X	X					0			
Bigelow HS	100	X	X	X	X		X	X	X	50	X	X		X	X					0			
Foley HS	100	X	X	X	X		X	X	X	50	X	X		X	X					0			
McCredie HS	100	X	X	X	X		X	X	X	50	X	X		X	X					0			
Wall Creek HS	100	X	X	X	X		X	X	X	50	X	X		X	X					0			
Beulah HS	160	X		X	X					0										0			
Jackies Butte Field	40	X			X					0										0			
Jordan Craters Field	57	X			X		X	X		0										0			
Little Valley Area	57	X			X		X	X		12				X						0			
Luce HS	100	X	X	X	X		X	X	X	12				X						0			
McDermitte	100	X	X	X	X		X	X	X	0										0			
Mitchell Butte	100	X	X	X	X		X	X	X	12				X						0			
Breiten Bush HS	100	X	X	X	X		X	X	X					X	X			X					
Medical HS	96	X	X	X	X		X	X															
Kahneeta HS	71	X		X	X					14				X									

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BINARY WELLHEAD SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: WASHINGTON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000' to 6,000' Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Mt. Baker	93	X	X	X	X			X	X	26	X	X								0			
Mt. Adams	93	X	N/A		X			X	X	13	N/A									0			
Puny Creek Basalt	100	X	N/A	X	X		X	X	X	39	N/A	X		X						0			

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Table 7.6 — Phase of Exploration - Binary Wellhead Sites - Washington

DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: IDAHO	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000' Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Boise	100	X	X	X	X		X	X	X	76	X	X	X	X	X		X			66	X	X	
Garden City	100	X	X	X	X		X	X	X	51	X	X	X				X			33	X		
Meridian	100	X	X	X	X		X	X	X	26		X	X							33	X		
Eagle	100	X	X	X	X		X	X	X	26		X	X							33	X		
Kuna	100	X	X	X	X		X	X	X	26		X	X							33	X		
Council	100	X	X	X	X		X	X	X	26		X	X							33	X		
Chubbuck	100	X	X	X	X		X	X	X	63	X	X	X		X		X			33	X		
Pocatello	100	X	X	X	X		X	X	X	76	X	X	X	X	X		X			33	X		
Lava Hot Springs	93	X	X	X	X		X		X	39	X	X	X							0			
Hailey	86	X	X	X	X				X	64	X	X	X	X	X					0			
Ketchum	86	X	X	X	X				X	64	X	X	X	X	X					0			
Idaho City	94	X	X	X	X		X	X		13		X								0			
Idaho Falls	93	X	X	X	X		X		X	13		X								0			
Ammon	93	X	X	X	X		X		X	13		X								0			
Butte City	100	X	X	X	X		X	X	X	13		X								33	X		
Fairfield	94	X	X	X	X				X	39	X	X	X							33	X		
Caldwell	100	X	X	X	X		X	X	X	16	X	X	X	X	X		X			33	X		
Melba	93	X	X	X	X		X		X	26		X	X							33	X		
Nampa	100	X	X	X	X		X	X	X	64	X	X	X	X	X					33	X		
Parma	100	X	X	X	X		X	X	X	26		X	X							33	X		
Soda Springs	100	X	X	X	X		X	X	X	64	X	X	X	X	X					33	X		
Challis	80	X	X	X	X					39	X	X	X							33	X		

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Table 7.7 — Phase of Exploration - Direct Utilization Sites - Idaho

DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: IDAHO	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Stanley	60	X		X	X					26		X	X							0			
Glenns Ferry	87	X	X	X	X		X			39	X	X	X							33	X		
Mountain Home	100	X	X	X	X		X	X	X	39	X	X	X							33	X		
Mountain Home AFB	100	X	X	X	X		X	X	X	64	X	X	X	X			X			33	X		
Preston	100	X	X	X	X		X	X	X	52	X	X	X	X						33	X		
Ashton	93	X	X	X	X		X		X	39	X	X	X							33	X		
Emmett	100	X	X	X	X		X	X	X	39	X	X	X							0			
Rexburg	80	X		X	X		X	X	X	52	X	X	X	X						33	X		
Paul	93	X	X	X	X		X		X	0										0			
Malad City	86	X	X	X	X				X	39	X	X	X							33	X		
Grand View	100	X	X	X	X		X	X	X	39		X	X	X						33	X		
Homedale	100	X	X	X	X		X	X	X	0										33	X		
Payette	100	X	X	X	X		X	X	X	0										33	X		
American Falls	100	X	X	X	X		X	X	X	13		X								33	X		
Buhl	100	X	X	X	X		X	X	X	39	X	X	X							33	X		
Filer	100	X	X	X	X		X	X	X	39	X	X	X							33	X		
Hansen	100	X	X	X	X		X	X	X	0										33	X		
Kimberly	100	X	X	X	X		X	X	X	0										33	X		
Twin Falls	93	X	X	X	X		X		X	39	X	X	X							33	X		
Cascade	80	X	X	X	X					52	X	X	X	X						0			
Midvale	87	X	X	X	X		X			26		X	X							33	X		
Weiser	87	X	X	X	X		X			52	X	X	X	X						0			

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DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: MONTANA	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:				PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:				PHASE III—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
							Heat Flow	Gradients	Gravity								Gradients	Electrical	Seismic				
Emmigrant	67	X		X	X		X			0										0			
Bozeman	73	X		X	X		X		X	62		X	X		X			X	X	33		X	
Warm Springs	67	X		X	X		X			49		X			X			X	X	0			
White Sulfur Springs	67	X		X	X		X			26		X		X						0			
Clancy	47	X		X			X			12								X		0			
Whitehall	47	X		X			X			0										0			
Hot Springs	73	X		X	X		X		X	25				X				X		66	X	X	
Polaris	27	X					X			0										0			
Camas	67	X		X	X		X			29								X	X	0			
Grantsdale	47	X		X			X			0										0			
Anaconda	47	X		X			X			0										0			
Deer Lodge	27	X					X			0										0			
Townsend	67	X		X	X		X			0										0			
Lolo	47	X		X			X			0										0			
Avon	47	X		X			X			0										0			
Livingstone	67	X		X	X		X			13				X						0			
Gardiner	67	X		X	X		X			13				X						0			
Sula	47	X		X			X			0										0			
Garrison	47	X		X			X			0										0			
Paradise	47	X		X			X			0										0			

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Table 7.8 — Phase of Exploration - Direct Utilization Sites - Montana

DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT
OCTOBER 1984

STATE: OREGON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
North Powder	94	X	X	X	X		X	X		0										0			
Haines	94	X	X	X	X		X	X		0										0			
Baker	94	X	X	X	X		X	X		12				X						0			
Huntington Area	94	X	X	X	X		X	X		12				X						0			
Government Camp	100	X	X	X	X		X	X	X	76	X	X	X	X	X		X			33	X		
Arlington	74	X	X		X		X	X		0										0			
Ritter Hot Springs	94	X	X	X	X		X	X		0										0			
Burns Area	100	X	X	X	X		X	X	X	25	X			X						0			
Parkdale	100	X	X	X	X		X	X	X	12					X					0			
Ashland	94	X	X	X	X		X	X		63	X	X		X			X			0			
Klamath Falls Area	100	X	X	X	X		X	X	X	100	X	X	X	X	X		X	X	N/A	100	X	X	X
Paisley Area	94	X	X	X	X		X	X		0										0			
Lakeview Area	100	X	X	X	X		X	X	X	26	X	X								0			
Oakridge Area	100	X	X	X	X		X	X	X	26	X	X								0			
Vale Area	100	X	X	X	X		X	X	X	75	X	X		X			X	X	X	0			
Ontario Area	100	X	X	X	X		X	X	X	0										0			
Adrian Area	100	X	X	X	X		X	X	X	12				X						0			
Jordan Valley	74	X	X		X		X	X		12				X						0			
Boardman Area	74	X	X		X		X	X		0										0			
Heppner Area	40	X			X					0										0			
Irrigon Area	74	X	X		X		X	X		0										0			
Lexington Area	40			X						0										0			

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Table 7.9 — Phase of Exploration - Direct Utilization Sites - Oregon

DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: OREGON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Reglonal Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEOTHERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Troutdale Area	94	X	X	X	X		X	X		0										0			
Athena	74	X	X		X		X	X		0										0			
Echo	40	X			X					0										0			
Hermiston	74	X	X		X		X	X		0										0			
Milton-Freewater	74	X	X		X		X	X		0										0			
Pendleton	74	X	X		X		X	X		0										0			
Pilot Rock	74	X	X		X		X	X		0										0			
Stanfield	74	X	X		X		X	X		0										0			
Umatilla	74	X	X		X		X	X		0										0			
Weston	74	X	X		X		X	X		0										0			
Imbler Area	94	X	X	X	X		X	X		12				X						0			
La Grande Area	94	X	X	X	X		X	X		12				X						0			
Cove Area	94	X	X	X	X		X	X		12				X						0			
Union Area	94	X	X	X	X		X	X		12				X						0			
Kahneeta Hot Springs	60	X		X	X					0										0			
Rajneeshpuram	74	X	X		X		X	X		0										0			
The Dalles	94	X	X	X	X		X	X		0										0			
Spray City Well	60	X	X		X					0										0			

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DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: WASHINGTON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement in All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Connell/Cunningham	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Lind	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Othello	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Ritzville	100	X	X	X	X		X	X	X	38			X	X	X					0			
Washtucna	100	X	X	X	X		X	X	X	38			X	X	X					0			
Clarkston	100	X	X	X	X		X	X	X	13			X							33	X		
Benton City	100	X	X	X	X		X	X	X	38			X	X	X					0			
Kennewick	100	X	X	X	X		X	X	X	38			X	X	X					0			
Prosser	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Richland	100	X	X	X	X		X	X	X	62			X	X	X			X	X	33	X		
West Richland	100	X	X	X	X		X	X	X	62			X	X	X			X	X	33	X		
Wenatchee/East Wenatchee	100	X	X	X	X		X	X	X	25				X	X					33	X		
Pasco	100	X	X	X	X		X	X	X	62			X	X	X			X	X	33	X		
Pomeroy	100	X	X	X	X		X	X	X	13			X							33	X		
Ephrata	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Moses Lake	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Soap Lake	100	X	X	X	X		X	X	X	25				X	X					0			
Warden	100	X	X	X	X		X	X	X	25				X	X					33	X		
Ellensburg	100	X	X	X	X		X	X	X	38			X	X	X					33	X		
Wahkiacus	100	X	X	X	X		X	X	X	25			X		X					0			
Davenport	100	X	X	X	X		X	X	X	13			X							0			
Odessa	100	X	X	X	X		X	X	X	26			X	X						0			

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Table 7.10 — Phase of Exploration - Direct Utilization Sites - Washington

DIRECT UTILIZATION SITES
STATUS OF EXPLORATION & ASSESSMENT

OCTOBER 1984

STATE: WASHINGTON	PHASE I—REGIONAL RECONNAISSANCE	Literature Search	Temperature Gradient Measurement in Existing Wells: Wide Spacing	Spring, Well Sampling and Analyses of Ground Water: Wide Spacing	Broad Reconnaissance Geologic Mapping, 1:100,000 Scale or Smaller	Regional Geophysical Studies:	Heat Flow	Gradients	Gravity	PHASE II—INITIAL DIRECT EXPLORATION OF IDENTIFIED RESOURCE	Temperature Gradient Measurement In All Available Wells	Sampling of All Available Wells and Springs and Interpretation of Results	Qualitative and Quantitative Hydrologic Analysis	Detailed Geologic Mapping, 1:62,500 Scale or Larger	Lineament Analysis	Detailed Geophysical Exploration:	Gradients	Electrical	Seismic	PHASE III—DIRECT TESTING OF GEO-THERMAL RESOURCE AT DEPTH	Deep drilling of 1,000 to 6,000 Wells to Test Aquifer	Reservoir Testing Evaluation Including Pump Testing	Quantitative Reservoir Estimation
Reardon	100	X	X	X	X		X	X	X	26			X	X						0			
St. Martin's Hot Springs Resort	100	X	X	X	X		X	X	X	38			X	X	X					0			
N. Bonneville	100	X	X	X	X		X	X	X	100	X	X	X	X	X		X	X	X	33	X		
Stevenson	100	X	X	X	X		X	X	X	38			X	X	X					0			
Cheney	100	X	X	X	X		X	X	X	26			X	X						33	X		
Walla Walla/College Place	100	X	X	X	X		X	X	X	26			X	X						33	X		
Colfax	93	X	X	X	X			X	X	26			X	X						0			
Pullman	93	X	X	X	X			X	X	26			X	X						0			
Granger	93	X	X	X	X			X	X	26			X	X						33	X		
Grandview	93	X	X	X	X			X	X	26			X	X						33	X		
Harrah	93	X	X	X	X			X	X	26			X	X						33	X		
Mabton	93	X	X	X	X			X	X	26			X	X						33	X		
Sunnyside	93	X	X	X	X			X	X	26			X	X						33	X		
Toppenish	93	X	X	X	X			X	X	26			X	X						33	X		
Yakima Area	93	X	X	X	X			X	X	26			X	X						33	X		
Zillah	93	X	X	X	X			X	X	26			X	X						33	X		

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TABLE 7.11 - Costs of Exploration

ELECTRICAL GENERATION SITES

		Cascades	Basin & Range
PHASE I			
1.	Literature Search	$ 1,750	$ 1,750
2.	Temp. Grad. Measurement - Existing Wells - Wide Spacing	7,000	7,000
3.	Spring Sampling - Wide Spacing	8,500	8,500
4.	Reconnaissance Geologic Mapping	10,750	10,750
5.	Regional Geophysics		
	a. Heat Flow and Temp. Grads.	5,000	5,000
	b. Gravity	36,000	36,000
	c. Aeromagnetics	9,600	9,600
	d. Electrical (Regional Magnetotellurics)	80,000	80,000
	e. Seismic	N/A	N/A
	TOTAL	$ 158,600	$158,600
PHASE II			
1.	Temp. Grad. Measurement - All Wells	$ 3,500	$ 3,500
2.	Sampling		
	a. All Springs and Wells (incl. interpretation)	8,250	8,250
	b. Soil Sampling (Mercury)	15,500	15,500
	c. Gas Sampling (Radon)	1,000	1,000
	d. Cold Water Sampling	1,500	1,500
3.	Qual. and Quan. Hydrologic Analysis	9,000	9,000
4.	Detailed Geologic Mapping	38,250	29,000
5.	Lineament Analysis	2,500	2,500
6.	"Shallow" Temp. Gradient Wells	1,500,000	150,000
7.	Geophysics		
	a. Heat Flow and Temp. Grads.	7,500	7,500
	b. Gravity	10,000	10,000
	c. Magnetics (Ground)	4,500	4,500
	d. Electrical	51,500	51,500
	e. Seismic	N/A	400,000
	TOTALS	$1,653,000	$694,250
PHASE III			
1.	Intermediate depth drilling	N/A	$1,150,000
2.	Quantitative Hydrologic Modeling	$ 30,000	30,000
	TOTALS	$ 30,000	$1,180,000
PHASE IV			
1.	Deep Drilling to Test Aquifer	$1,000,000	$1,000,000
2.	Reservoir Testing and evaluation	160,000	160,000
3.	Quantitative Reservoir Estimation	7,500	7,500
	TOTAL	$1,167,500	$1,167,600
	GRAND TOTAL	$3,009,100	$3,200,350

TABLE 7.12 - Costs of Exploration

DIRECT UTILIZATION AND BINARY WELLHEAD SITES

PHASE I		
1.	Literature Search	$ 1,750
2.	Temp. Grad. Measurements - Existing Wells - Wide Spacing	7,000
3.	Spring and Well Sampling and Analysis - Wide Spacing	8,500
4.	Reconnaissance Geologic Mapping	10,750
5.	Geophysics	
	a. Heat Flow and Temp. Grad	5,000
	b. Gravity	36,000
	TOTAL	$ 69,000
PHASE II		
1.	Temp. Grad. Measurement - All Well	$ 3,500
2.	Spring and Well Sampling - Analysis and Interpretation	8,250
3.	Qualitative and Quantitative Hydrologic Analysis	9,000
4.	Detailed Geologic Mapping	29,500
5.	Lineament Analysis	2,500
6.	Geophysics	
	a. Temp. Grad. and Heat Flow	7,500
	b. Electrical	30,500
	c. Seismic	NA
	TOTAL	$ 90,750
PHASE III		
1.	Deep Drilling to Test Aquifer	$200,000
2.	Reservoir Testing and Evaluation - Including Pump Testing	34,000
3.	Quantitative Reservoir Estimation	3,750
	TOTAL	$237,750
	GRAND TOTAL	397,500

CHAPTER 8

Electrical Generation Site Analysis

8.0 ELECTRICAL GENERATION SITE ANALYSIS

8.1 Introduction

The Geothermal Assessment Team has systematically characterized known and inferred moderate to high temperature geothermal sites in the BPA service area. This characterization of electric generation resource sites is one of four tasks which have been performed by the Assessment Group for Bonneville. Six steps were involved in the task: 1) development of a consistent regional methodology for the interpretation of geologic/geophysical data and estimating resource potential, 2) development of a list of sites to be subsequently ranked for degree of developability, 3) development of a detailed site description, 4) characterization of each specific site potential, 5) development of typical site configurations, and 6) development of estimates of energy potential, development cost, and energy costs for each site.

Existing information was used to characterize sites in Idaho, Montana, Oregon, and Washington. From an original 1,265 sites, 100 passed temperature and land use screens (see Chapter 2) for electrical generation. First, sites were required to have estimated reservoir temperatures above 90°C (194°F). Second, sites in legally-designated areas, e.g., hot springs in a wildlife refuge, National Parks, or national monuments were dropped from consideration. Remaining sites subsequently were listed, analyzed, and ranked for degree of developability (see Chapter 6). The assessment team assigned typical site configurations from known or estimated temperature data. This allowed engineering estimates of capital and operating costs to be developed for each site. Finally, engineering estimates were fed into an economic model which resulted in levelized energy cost estimates.

The objective of the characterization work was to develop generic capital and operation and maintenance (O&M) costs for geothermal wells, wellfield surface facilities, and power plants with capacities of less than 1 MW to 100 MW net. Cost data were derived from a variety of sources familiar with actual costs of existing wells, plants, and facilities. Bechtel National, Inc., and the Oregon Institute of Technology furnished engineering cost information used for screening the various geothermal resource prospects. In this way, realistic generic estimates for facility costs were used in the economic screening phase of the overall study. All engineering costs were computed in

September 1984 dollars, while financial costs are given in levelized 1984 dollars.

Engineering cost information derived under this task was formatted in a personal computer spreadsheet program, LOTUS 123 (TM). Formulas providing equipment costs and operating costs were set up on the spreadsheet to accommodate site-specific inputs, e.g., resource temperature and depth, distance to transmission lines, etc.

A LOTUS 123 (TM) spreadsheet program was used to create a calculation sequence that performs the constant dollar levelized cost procedure. This method is strictly based on the BPA costing procedures, as explained further in the chapter.

8.2 Electric Generation Potential Methodology

8.2.1 Description

To assess the electrical generation potential and useful lifetime of a specific site, reliable estimates must be made of the amount of heat contained in the reservoir, the rate at which heat can be extracted, and the extent of recharge (Bodvarsson, et al., 1981). Where abundant production well data are available for a specific high temperature site, it is relatively easy to develop estimates of these parameters. It must be noted, however, that truly accurate models (and optimum reservoir extraction rates, rates of recharge, and lifetimes) can be developed only after production from the reservoir has been monitored for a significant period of time (i.e., a period of years). For example, at The Geysers steam field in Northern California, production is entering its 26th year. Yet, reservoir engineering models continue to be refined as new production data are made public.

If production data from one or two wells are available, and if the area of the field has been determined from geophysical and/or geologic techniques, then two rules-of-thumb are useful for estimating optimum well spacing in the field and the electrical generation potential of a discharging geothermal well (James, 1975a, 1975b). Assuming that conditions similar to those encountered in the production well(s) underlie

the whole reservoir, it is possible to estimate the potential of the entire field.

The above techniques work quite well if production well data are available. However, drillhole data are not available for the majority of the sites examined in this report. In this situation, an assessment technique presented in U.S. Geological Survey Circular 790 (Brook, et al., 1979) is the best procedure, and was used for those sites for which production well data do not exist.

The technique presented in USGS circular 790 determines: (1) the accessible resource base, (2) the resource, and (3) the amount of electricity that might be produced from the system. The accessible resource base is defined as the amount of geothermal energy within a specified volume of rock and at a specified temperature referenced to 15°C (59°F), (Brook et al., 1979). It is an estimate of the total amount of heat contained in the reservoir. The resource is that fraction of the accessible resource base that can be produced at the wellhead under reasonable assumptions of future technology and economics.

8.2.2 Summary

Accurate determinations of the electrical generation potential of a geothermal reservoir require detailed knowledge of reservoir volume, temperature, transmissivity, and rates of recharge.

If adequate production well data exist, relatively reliable estimates can be made for optimum well spacing in the field, and the expected electrical energy output for each well.

If production well data are limited or nonexistent, it is useful to apply the techniques and related assumptions of Brook et al., (1979) to estimate reservoir thermal energy, wellhead thermal energy, available work, and electrical energy for the reservoir of interest. This method is necessarily less precise than one based on production well data, but it is relatively conservative and provides useful estimates. The format of these

estimates allows us to refine specific sites as additional data become available. A full account of the methodology described above is set forth in Chapter 3 of this report.

8.3 Site Temperatures and Electric Potential

Moderate to high temperature resources, i.e., those capable of potentially generating electricity, have been examined by the Assessment Team after screening. Two primary screens were applied to all sites. As mentioned earlier, these were reservoir temperature (more than 90°C/194°F), and environmental sensitivity (also called legally-designated areas).

Several estimates of reservoir temperature were made using geothermometry, but only the **most likely** estimate was used in each case. Being located **in a legally-designated** area also screened sites from the list, while proximity to legally-designated areas is reflected in the ranking methodology (see Chapter 6). In addition, geologic evidence or insufficient data caused sites to be added to or to be removed from the list of sites. The resulting 100 sites are listed below by state with their estimated **most likely** reservoir temperatures and energy potential.

TABLE 8.1 - Site Temperatures and Electric Potential

County	Site	Location (T, R, S)	Estimated Geotherm Temp. (°C)	Estimated Energy (MW)
Idaho				
Adams	Krigbaum Hot Springs (HS)	19N 2E 22	145	0
	White Licks HS	16N 2E 33	97	2
Blaine	Guyer HS	4N 17E 15	90	0
Boise	Bonneville HS	10N 10E 31	94	0
	Deer Creek HS	9N 3E 25	139	2
Butte	Big Southern Butte	4-6N, 28-32E	-	-
Camas	Barron's HS	1S 13E 34	95	0
	Magic HS	1S 17E 23	140	2
	Worswick HS	1N 13E 32	90	0

County	Site	Location (T, R, S)	Estimated Geotherm Temp. (°C)	Estimated Energy (MW)
Idaho (Continued)				
Caribou	Blackfoot Lava Field	4-7S, 41-43E	230	1,715
Cassia	Raft River area	15S 26E 23	147	12
Custer	Sunbeam HS	11N 15E 19	94	0
Elmore	Latty HS	3S 10E 31	102	1
Franklin	Battle Creek HS	15S 39E 8	116	1
	Ben Meek Well	14S 34 36	97	0
	Maple Grove HS	13S 41E 7	106	1
	Squaw Creek HS	15S 39E 17	124	2
Fremont	Island Park Caldera*	10-12N, 40-45E	230	158,378
Gem	Roystone HS	7N 1E 8	135	2
Gooding	White Arrow HS	4S 13E 30	115	1
Idaho	Riggins HS	24N 2E	14	98
Lemhi	Big Creek HS	23N 18E 22	159	23
	Owl Creek HS	23N 17E 10	123	1
	Sharkey HS	20N 24E 34	107	1
Madison	Rexburg Caldera*	4-8N, 40-43E	230	102,873
Owyhee	Indian Creek HS	12S 7E 33	121	1
	Murphy Hot Springs	16S 9E 24	99	1
Valley	Boiling HS	12N 5E 22	100	0
	Cabarton HS	13N 4E 31	99	0
	Vulcan HS	14N 6E 11	97	0
Washington	Cove & Crane Cr.	10-11N 3W 7-9	163	179
Subtotal: 31				
Montana				
Beaverhead	Jackson HS	5S 15W 25	148	2
Deer Lodge	Gregson HS	3N 10W 2	126	1
Jefferson	Boulder HS	5N 4W 10	136	2
Lewis & Clark	Broadwater HS	10N 4W 28	98	0
	Marysville Well	12N 8W 32	117	4

County	Site	Location (T, R, S)	Estimated Geotherm Temp. (°C)	Estimated Energy (MW)
Montana (Continued)				
Madison	Ennis	5S 1W 28	135	2
	Norris HS	3S 1W 14	103	1
	Silver Star	2S 6W 1	135	2
Subtotal: 8				
Oregon				
Baker	Kropp Hot Spring	6S 39E 25	96	0
Clackamas	Austin HS	6S 7E 30	101	0
	Mt. Hood	2S 9E 29	134	5
Deschutes	Newberry Volcano	21-22S, 12-13E	258	1,557
	Bearwallow Butte	17S 10E	233	610
	China Hat/East Butte	22S 14E 10-12		0
	Frederick Butte	22S 19E 32	-	0
	Melvin/3-Creek Buttes	16S 9E	233	1,104
	Quartz Mountain	22S 15E 26		0
	Shukash Basin	21S 8E 15	-	-
Douglas	Umpqua HS	26S 4E 20	117	1
Grant	Blue Mountain HS	14S 34E 13	108	0
	Weberg HS	18S 26E 18	103	0
Harney	Alvord HS	34S 34E 32	231	28
	Borax Lake HS	37S 33E 11	231	66
	Crane HS	24S 33E 34	117	2
	Mickey HS	33S 35E 13	216	110
	O.J. Thomas well	22S 32E 35	102	1
	Trout Creek area	39S 37E 16	154	3
	Diamond Craters	28S 32E 33	-	-
Jackson	Mt. McLoughlin area*	36S 4E 14	185	14,078
	Rustler Peak	34S 4E 16	-	0
Klamath	Klamath Falls area	38S 9E	172	362
	Klamath Hills area	40S 9E 27	177	293
	Olene Gap HS	39S 10E 14	175	21
	Cappy-Burn Butte	26S 6-7E	233	378
	Crater Lake area*	30-32S 7-7 1/2E	185	36,241
Lake	Barry Ranch HS	39S 20E 4	139	1
	Crump HS	38S 24E 34	178	63
	Fischer HS	38S 25E 10	139	1
	Glass Buttes	23S 23E 27	233	278
	Hallinan Springs	40S 24E 29	140	2

County	Site	Location (T,	R,	S)	Estimated Geotherm Temp. (°C)	Estimated Energy (MW)
Oregon (Continued)						
	Lakeview area	39S	20E	4	144	8
	Summer Lake HS	33S	17E	18	142	4
	Cougar Peak	38S	18E	6	-	0
	Devils Garden area	24S	15E	17	-	0
	Four Craters area	25S	17E	34	-	0
	Squaw Ridge area	23S	16E	25	-	0
	Wart Peak Caldera	26S	12E	28	233	116
Lane	Belknap HS	16S	6E	11	113	1
	Bigelow HS	15S	6E	22	97	0
	Foley HS	16S	6E	28	100	1
	McCredie HS	21S	4E	36	98	0
	Wall Creek HS	20S	4E	26	93	0
Linn	Generic High Cascades	13S	6E		185	27
Malheur	Beulah HS	19S	37E	2	113	0
	Little Valley area	19S	43E	30	114	3
	Luce HS	24S	37E	20	118	1
	McDermitt area	40S	42E	23	91	0
	Mitchell Butte HS	21S	45E	12	93	0
	Neal HS	18S	43E	9	188	34
	Vale HS	18S	45E	20	155	130
	Jackies Butte Field	34S	42E	7	-	0
	Jordan Craters area	28S	43E	24	-	0
Marion	Breitenbush HS	9S	7E	20	109	1
Union	Medical HS	6S	41E	25	96	0
Wasco	Kahneeta HS	8S	13E	20	138	2
Subtotal: 57						
Washington						
Skamania	Puny Creek Basalt	5N	6E		-	-
Whatcom	Baker HS	38N	9E		-	2
	Mt. Baker	38N	7-8E		130	0
Yakima	Mt. Adams	8-9N	11E		-	-
Subtotal: 4						

Total Sites with Electric Potential: 100

* These sites are very much larger in area, contributing to their large power potential estimates.

8.4. Typical Site Configurations

8.4.1 Introduction

There are five main types of geothermal power conversion systems. They are: 1) dry or direct steam, 2) flashed steam, 3) binary, 4) rotary separator turbine, and 5) wellhead binary. Of these, the latter four will probably be the most commonly used technologies in the BPA service area.

Geothermal power conversion processes are dependent on steam content and temperature. Saturated steam or dry steam systems can be on the low end of the temperature scale, i.e., 175°C (350°F), but nevertheless are capable of driving turbines directly. All remaining conversion systems are based on resources where only a fraction of the total volume is steam. In the cases of flash, binary, and rotary separator turbine technologies, temperature is the controlling factor. Table 8.2 lists resource conditions and conversion technologies. Based on current information it is unlikely that

TABLE 8.2 - Resource Conditions and Conversion Processes

	Conversion Process				
Resource	Direct Steam	Single Flash	Double Flash	RST	Binary
Steam[1] (Similar to the Geysers) 175°C (350°F)	X				
Hot water[1] 277°C (530°F)		X	X	X	
Hot water[1] 216°C (420°F)		X	X	X	
Hot water[1] 177°C (350°F)			X	X	X
Hot water[2] 90-150°C (194-300°F)					X

1 Cost estimates following derived from Bechtel National, Inc., 1984.

2 Cost estimates following derived from OIT Geo-Heat Center, 1983, and Ryan, 1984.

rare, dry steam resources will be discovered in the Northwest. A brief description of all technologies and typical site development configurations follows.

8.4.2 Direct Steam Configuration

Dry steam systems are geothermal resources made up of saturated water vapor; they are called vapor-dominated systems. The method used to exploit a direct, dry steam resource is shown schematically in Figure 8.1. Steam from production wells drives a steam turbine which in turn drives a generator, and supplies electricity. The condensed liquid is then sent to injection wells. For the sake of simplicity, it is assumed here that the steam contains no non-condensable gases. Electricity generated is measured at the bus bar, with pump, fan, and other auxiliary loads subtracted. Well designed dry-steam power plants with condensing turbines operate with utilization efficiencies of between 50 and 60 percent, and with steam consumptions of about 8 kg/kWh (18 lb/kWh). However, it is appropriate only to measure thermodynamic utilization and not conventional power plant cycle efficiency. DiPippo (1980) provides a detailed analysis of geothermal power plant performance measurement.

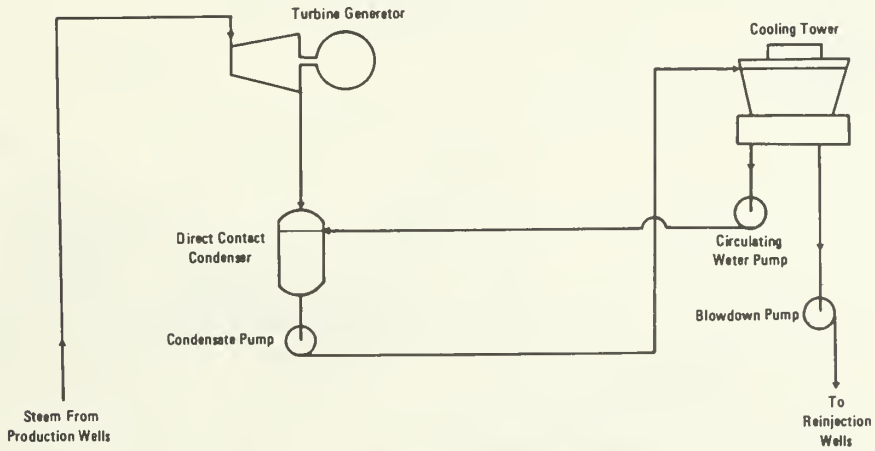


Figure 8.1 – Schematic plan of a geothermal power plant.

The cooling tower shown in Figure 8.1 discharges large quantities of vapor into the atmosphere. Cooling towers provide water at approximately 27°C (80°F) to the condensers, allowing efficient operation of condensing turbines. The condensed fluid is discharged through the injection wells.

Because as much as 80 percent of the flow passing through the turbine may be lost to the atmosphere, a careful water budget must be established for each plant. Alternatively, the cooling tower operation may be accounted for separately, and the control surface may be drawn through the supply and discharge line of the condenser. It should be noted that a cooling tower must be supplied with make-up water during normal operation . This make-up water usually is derived from steam condensate, and amounts to approximately 6.4 million liters (1.7 million gallons) per 55 MW of capacity per day. The make-up water stream is not marked in Figure 8.1.

An elevation view of Units 1 and 2 at The Geysers, California, is shown in Figure 8.2. These units are basic in design and do not account for emission controls. Units 1 and 2 represent the technology of the years 1960 to 1963. They are rated at 11 and 13 MW, respectively, and occupy less than 2 hectares (five acres).

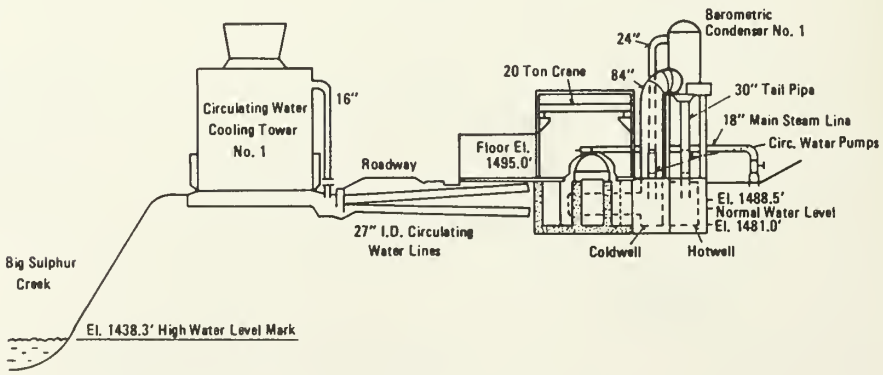


Figure 8.2 – Elevation view of Units 1 and 2, the Geysers, California.

A schematic of The Geysers Unit 14, a more environmentally sophisticated unit, is shown in Figure 8.3. Built in 1980, this 110 MW plant occupies approximately 6 hectares (15 acres).

Steam gathering systems at The Geysers are no longer than 2 km (6,650 ft.) to control loss of availability of the steam from the wellhead to the turbine. Gathering pipe diameters range from 254 mm (10 in.) at the wellhead to 914 mm (36 in.) at the plant. A steam well will supply anywhere from 34,000-159,000 kilograms per hour kg/h (75,000-350,000 lb/h). Approximately seven production wells are connected to the system supplying the required 450 metric tons per hour (t/hr) (1,000,000 lb/hr) of steam for a typical 55 MW power plant. Half the number of production wells, e.g., four wells, are generally required for injection at typical 55 MW plants in The Geysers.

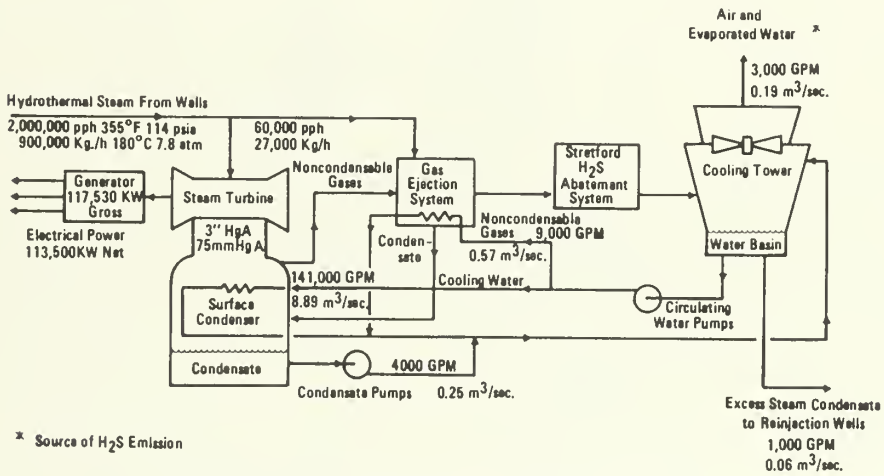


Figure 8.3 – Schematic flow diagram for Unit 14, the Geysers, California.

8.4.3 Flashed Steam Configuration

Dry steam or vapor-dominated systems are rare. There are only five dry system fields which have been developed in the world. Hot water or liquid-dominated geothermal systems are much more common. These systems contain small amounts of steam, but most of the resource is under pressure in the fluid phase. Fluid is brought to the surface and piped into a flash vessel, where it expands into separate steam and fluid phases.

A flash power conversion system which separates the fluid mixture into streams of vapor and liquid is shown schematically in Figure 8.4. After flashing, the single-flash system is similar to the system shown in Figure 8.1. Both the separated brine and the spent condensate are exhausted from this system for injection.

The efficiency of flash plants is substantially lower than that of dry steam plants. This is due to the small amount of steam available in the resource, and because the hot water fraction of the mixture is discarded from the plant without being used. In an effort to fully utilize these liquid-dominated resources, additional flash stages can be added to the process. The result is a double-, triple-, or multi-flash system which more fully utilizes these liquid-dominated resources.

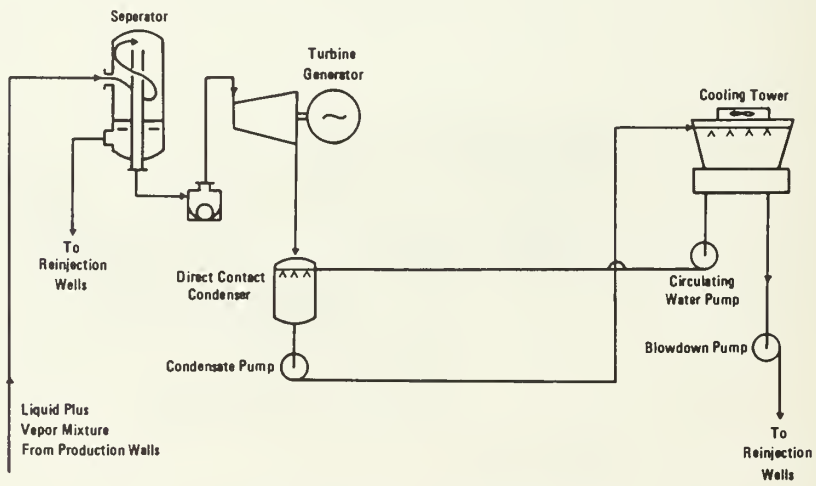


Figure 8.4 — Flash conversion system for geothermal power plants.

The double-flash system is shown schematically in Figure 8.5. A high-pressure, high-temperature fluid from the well separates into a mixture of steam and liquid, then the liquid is throttled in the flash vessel to produce additional streams of vapor and liquid at lower pressure. The steam from both the separator and the second stage flash tank goes to the turbogenerator, while the liquid is injected into the reservoir. Ultimately, the steam is injected as condensate after passing through the condenser and cooling tower. The latter loses fluid as before.

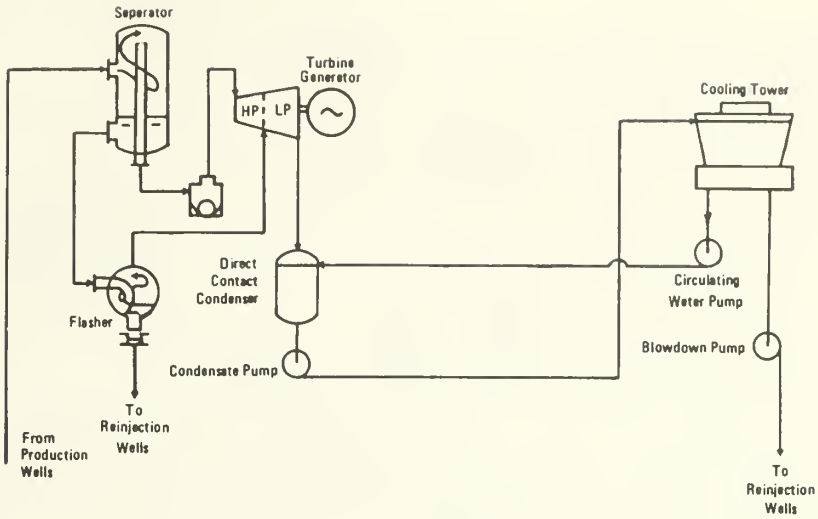


Figure 8.5 – The double-flash conversion system for geothermal power plants.

Existing power plants in southern California provide good examples of typical flash steam configurations. Other larger plants exist in Mexico; however, it is felt that the smaller demonstration plants use technology more appropriate to the Northwest.

The Brawley 10 MW flash plant in California, a joint effort of Union Oil Company and Southern California Edison, uses a flashed steam system (Figure 8.6). Here geothermal fluids are brought to the surface under pressure and moved through a succession of flash vessels where the pressure is reduced, allowing a portion of the fluid at each vessel to separate into steam. This steam is delivered to Edison at a design rate of 94,800 kg/hr (209,000 lbs/hr) at a single pressure, 115 psia at an approximate saturation temperature of 170°C (340°F). The remaining brine, with its high concentration of dissolved solids, is injected back into the ground. Non-condensable gases are removed from the condenser by a steam-jet ejector, then vented. Preliminary results indicate evaporative water demands on the same order as The Geysers plants, i.e., 300 gpm per 10 MW of capacity.

The Brawley turbine (Figure 8.6) is a 10,000 kW, 3,600 rpm, single flow, single cylinder unit with five impulse stages. The unit was first designed as portable, thus the turbine generator was built as a single, skid-mounted unit, installed at grade, with a top exhaust and overhead crossover exhaust duct to a condenser located on the side.

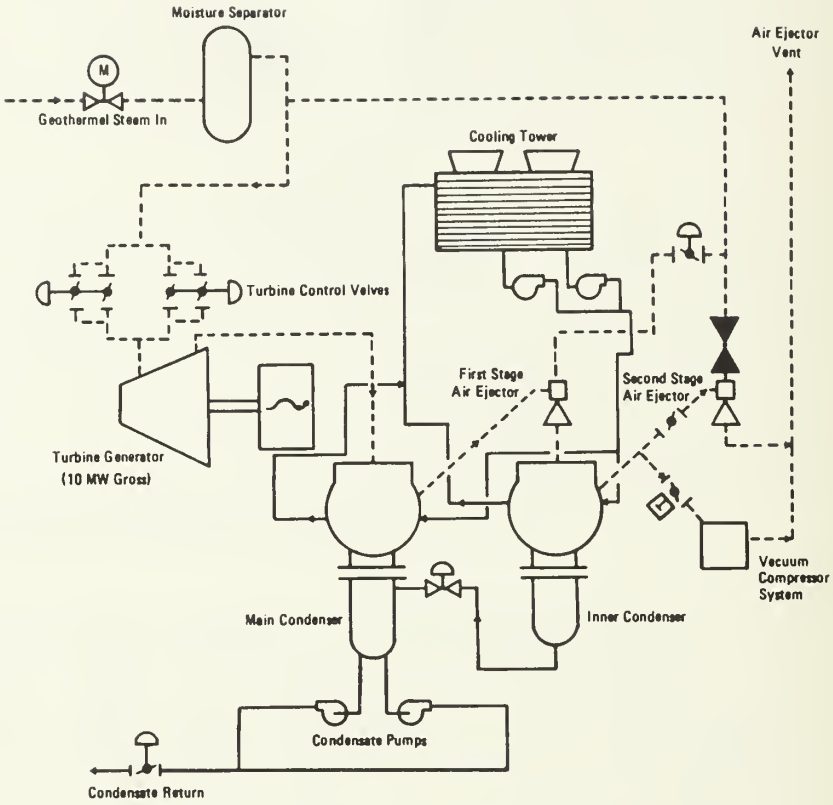


Figure 8.6 – Brawley 10 MW process flow diagram.

A shell and tube condenser have been provided because it is desirable to retain the steam condensate for process use. Corrosion resistant stainless steel materials are used because of the oxidation potential of air, oxygen, and hydrogen sulfide in the system.

A conventional two cell, induced draft, counterflow, wet cooling tower provides cooling water. Each cell has a 22 foot diameter fan. The concrete tower basin is epoxy-coated for protection in the event that condensate is used for makeup at a later date.

Auxiliary or parasitic plant loads at the Brawley 10,000 kW turbine total about 1 MW (10 percent of gross capacity). The plant has been operating at 50 to 60 percent of capacity. Net plant output is sold to a local electric utility. Data gained from the operation of this plant will help determine the design of a 50 MW or 100 MW commercial power plant at Brawley. The Brawley site occupies 5 hectares (12 acres), including 6 production and injection well sites.

8.4.4 Binary Configuration

Rather than use steam directly to drive a turbine, binary generation systems use secondary working fluids to drive turbines. These systems pipe the resource to a heat exchanger, vaporizing a secondary fluid which then drives a turbine. This working fluid is organic and has several advantages: higher efficiency than steam at low temperatures, non-corrosive working fluid in the turbine, and less expensive turbine for a given output. The resource passes through the heat exchanger and is injected back into the ground. Such "closed loop" systems do not expose the geothermal resource to air, water, or the surface resulting in significant environment attractiveness. Geothermal resources as low as 90°C (194°F) can use the organic Rankine cycle to convert heat into electricity. Figure 8.7 shows a binary system schematic.

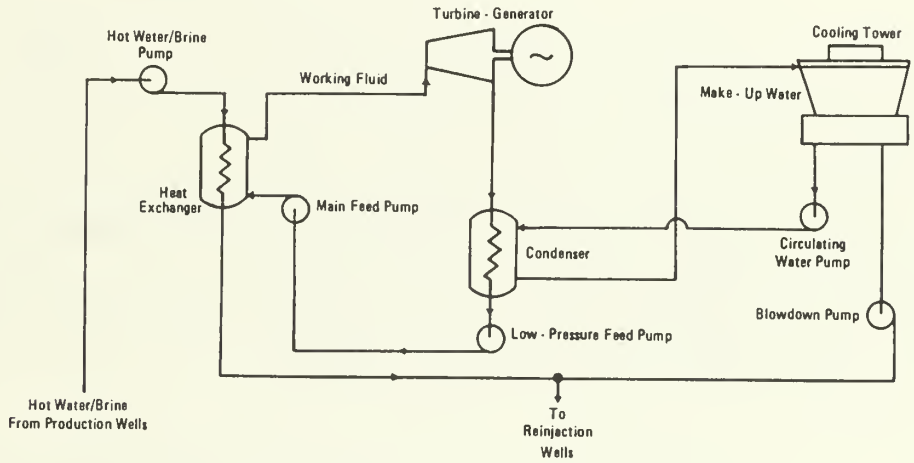


Figure 8.7 – Binary geothermal power plant.

In the organic Rankine cycle, a halocarbon or hydrocarbon working fluid (chosen according to resource temperature), is vaporized by the heat stream in the heat exchanger. The pressurized vapor expands through the organic vapor turbine which is coupled to a generator. The low pressure turbine exhaust passes through the condenser, and the resultant fluid is pumped to the vaporizer by the working fluid cycle pump.

The use of flammable working fluids necessitates fire protection equipment and safeguards not normally associated with the steam power plants. This equipment results in additional costs to the power plant.

The efficiency of the Rankine cycle is low because resources used in this application possess low enthalpy (low intrinsic heat content), and a secondary conversion process is involved. Achievable efficiencies of the organic Rankine cycle range from approximately 3 to 18 percent.

The Casa Diablo 7 MW binary plant, under construction in Mono County, California, provides one example. In this project, resource, environmental, and base load design considerations led to the choice of a simple binary cycle plant employing 100 percent air cooling. The geothermal fluid is maintained in a liquid state throughout, and 100 percent of the fluid is injected. Moreover, no cooling water is required in an area where fresh water is at a premium.

At Casa Diablo, geothermal brine at 165°C (330°F) is pumped from four production wells, using vertical line-shaft turbine pumps, to the heat exchangers. Cooled brine leaves the heat exchangers and is pressurized for injection into two wells by centrifugal pumps at the plant site.

A fluorocarbon, isobutane, is the working fluid in this plant. Turbine exhaust is condensed in the air coolers. The design is based on the use of carbon steel heat exchangers and condensers. Conventional carbon steel is cheaper than exotic metal alloy alternatives and in this instance requires no special fluid handling.

Air cooling also permits advantageous use of cold air as a cooling medium, particularly in the wintertime, thereby increasing thermal efficiency and power output by reducing condensing pressures in the season when power is most needed. Parasitic loads are estimated to average 2.4 MW (32 percent of gross capacity) on a yearly basis.

Operation using the "floating mode" concept will result in varying power outputs throughout the year. Floating mode refers to sizing equipment to take advantage of varying atmospheric temperatures. Power output during the coldest winter months will be about 30 percent higher than output during the warmest summer months. Monthly average production will be near 8 MW during the winter with low air temperatures and low turbine back pressures. Power during the summer will be about 6 MW due

to higher turbine back pressures and off-design operation. The total annual power output is higher using this floating mode than if a single high air temperature were chosen as the design point for year-round operation.

Low plant construction costs, e.g., $1,400/kW, and high reliability are ensured by building twin units, each with a capacity of 3.5 MW calculated on a yearly basis. Construction at Casa Diablo took approximately 14 months, ending in September 1984. The facility occupies approximately 4 hectares (10 acres).

The Casa Diablo plant is intended to demonstrate modular construction (maximizing both portability and salvage value), quick construction, and commercial viability.

8.4.5 Wellhead Binary Configuration

The difference between wellhead binary plants and simple binary plants is size and portability. Plants up to 10 MW in size have been called wellhead binary, all others simply binary. Although wellhead flash systems are available, binary systems offer greater promise of development due to the wider range of operating temperatures. Advantages of small binary power plants over large (55 MW) plants are several: smaller capital investment; short time for design, procurement and construction; modular construction; and reduced resource, technical, and institutional risks.

The only regional installation of wellhead binary power generation equipment is in Lakeview, Oregon. There, resources developed by Northwest Geothermal Corporation supply equipment operated by Wood & Associates. Any electricity produced is sold to Pacific Power & Light. Both SPS and ORMAT (company names) units are installed at the site, but only the ORMAT equipment is examined in this report. The Lakeview plant, schematically shown in Figure 8.8, is outlined in detail due to the likelihood of similar installations occurring in the BPA service area.

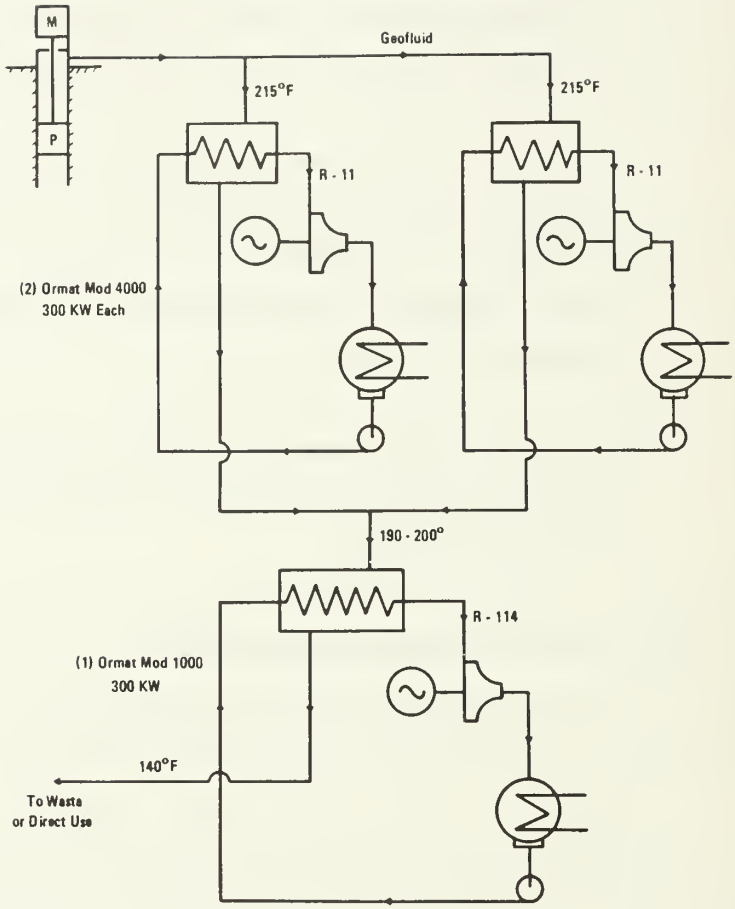


Figure 8.8 – Organic Rankine cycle geothermal power plant.
(ORMAT binary power plant.)

At the Lakeview facility, the geothermal water supply comes from a 209 meter (685 ft.) deep well capable of producing over 3,400 liters (900 gallons) per minute of 101°C (214°F) fluid. The resource contains approximately 700 ppm total dissolved solids. The static water level is 29 meters (95 ft.) below the surface. The resource is brought to the surface by a 100 hp, line-shaft driven, 12-stage pump set at 59 meters (180 ft.). Fluid from this well is piped approximately 700 meters (2,150 ft) to the facility site. There, three Israeli-made ORMAT binary power plants use the resource to generate a maximum 900 kW. Two of the ORMAT units are Model 4000, rated at 300 kW, and one, Model 1000, rated at 300 kW. Model 1000 operates on lower temperature water but at higher flow rates, and runs on the exhaust water from the two Model 4000 units. The working fluids are Refrigerant 11 and 114 for the Model 4000 and 1000, respectively.

The Lakeview resource is supplied to heat exchangers of the R-11 units at 101°C (214°F) and discharges into the R-114 unit heat exchanger at approximately 90°C (194°F). The fluid temperature leaving the plant is less than 60°C (140°F). The three units are serviced by water-cooled, surface-type condensers prior to cooling. Cooling for the units is provided by a 12,500 square meter (3 acre) riffle system and a cooling pond. The pond, approximately 30 meters by 11 meters and 2 meters deep, provides adequate capacity during cool months. During the warm months, a cooling tower will likely be needed. Geothermal water supplies the cooling water make-up, but may be replaced with cold, shallow groundwater in the future.

The ORMAT units consist of custom-built heat exchangers, turbogenerator, and electrical switch gear. Each unit is estimated to cost between $1,000-1,500/kW. Exact costs are confidential. Each complete unit is built into a skid-mounted container approximately 12 meters long, 2 meters high, and 2 meters wide (40' x 8' x 8'). The units are assembled at the factory and tested prior to delivery. Procurement and installation at Lakeview took less than one year. The facility site occupies approximately 3 hectares (8 acres).

8.4.6 Rotary Separator Turbine

The rotary separator turbine (RST) appears to be the most promising of the "total flow" technologies. The RST is designed to separate steam and gas from liquid, generate electricity, and repressurize the liquid. The separator, shown in Figure 8.9, works like a cyclone separator with liquid accumulating on the rotating RST walls. A scoop immersed in the liquid serves as a liquid turbine to generate power.

Separated steam is then available for expansion through a steam turbine. The device's designers estimate that more than 50 percent of the kinetic energy from the nozzle expansion can be recovered by the RST. This results in approximately 20 percent more total power than a single stage flash steam plant can produce from a medium temperature resource.

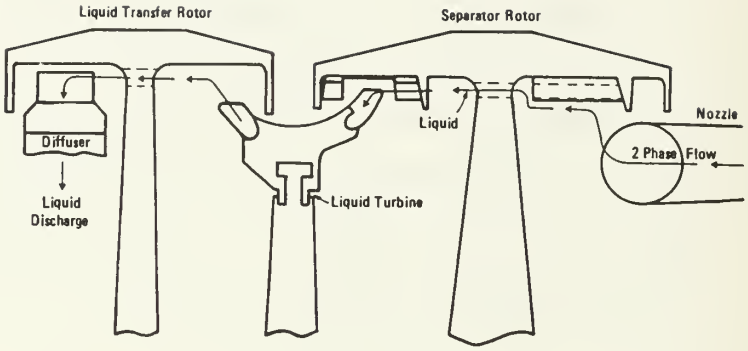


Figure 8.9 – Schematic diagram of the rotary separator turbine.

Power plants are offered in the 5 to 20 MW range for resources above 149°C (300°F). Maximum flow capacity is approximately one million pounds per hour. The costs for the wellhead plants are comparable to other systems for high temperature liquid-dominated resources (260°C/500°F). Such plants typically process 432,000 kg/h (950,000 lb/h) of total flow with a net output of 13 MW.

A 1.6 MW unit has been tested at Roosevelt Hot Springs, Utah, since November 1981. The tests demonstrated the ability of the 54-inch RST with full wellflow input of 227,000 kg/h (540,000 lb/h) at 404 psia, to produce the design liquid power output of 1.6 MW. The RST steam output of 57,000 kg/h (126,000 lb/h) at 43 psia would have produced an additional output of 6.1 MW if expanded through a steam turbine to 2 psia. The RST was operated for 4,000 hours with a gross power output of 3,270 megawatt-hours (MWh) and a net output of 2,612 MWh. The measured power output established the capability of the RST unit to produce more power per unit of flow than conventional single flash steam plants. As a result of the successful test in Utah, a 14 MW system is being installed at Roosevelt for commercial operation by Utah Power and Light.

8.5 Cost Estimates

8.5.1 Introduction

The objective of the characterization work is to develop generic capital and operation and maintenance (O&M) costs for geothermal wells, wellfield surface facilities, and power plants for a range of plant capacities from less than 1 MW to 100 MW net. Costs also include exploration work prior to development, based on tasks discussed in Chapter 7. Well cost estimates have been analyzed by the Assessment Team and conservative figures chosen. Bechtel National, Inc., and the Oregon Institute of Technology furnished wellfield and plant cost information used for economic ranking of the various geothermal resource prospects. Transmission line costs were supplied by BPA. In this way, realistic estimates of generic facility costs are used in the economic ranking phase of the overall study.

Historically, two parties have been involved in resource supply and power generation, respectively. However, both utilities and developers agree that the ability to construct power plants is no longer strictly a utility function. (Based on recent experiences in California, utilities may evolve into electricity distributors rather than suppliers.)

We have therefore determined total facility capital costs, including wells, from the positions of both the developer (be it independent or a utility) and the ratepayer. Total costs are important to both parties. Because of the need for total capital cost estimates, resource supply and power generation costs were included together. Assuming one entity constructs both fuel supply (wells and wellfield equipment) and the power plant, operating fuel costs would be zero.

The economic runs used here assume one developer. In a supplier/utility arrangement total capital costs would be reduced approximately two thirds, and well costs would be recovered by the supplier (with a profit) through operating fuel costs. The cost component format used in this project allows for such estimates to be undertaken in the future.

Engineering cost information derived by this task is formatted on a personal computer spreadsheet program, LOTUS 123 (TM). In the course of programming the cost formulas, the team modified the inputs and outputs to include additional conservative cost estimates. Additional costs include assessment work, wells, transmission lines, and contingencies. These additions have been combined with formulas providing equipment and operating costs. Finally, all work has been set up on the spreadsheet to accommodate site-specific inputs. Costs are given in September 1984 dollars, and may be updated by the Handy-Whitman steam generation construction cost index.

8.5.2 Remaining Assessment Work

Given that prudent developers try to verify as much as possible the existence of a resource prior to actual well drilling, this remaining assessment work must be included in total development costs. As discussed in Chapter 7, exploration work includes passive techniques such as mapping, sampling existing spring, geochemical analyses, and varying levels and types of geophysical surveys. Also included is shallow temperature gradient drilling. Conservative costs have been estimated for each exploration phase and task, as shown in Table 7.11.

A matrix indicating completed assessment work for each site has been compiled (see Tables 7.1 to 7.6). The remaining assessment work has been noted and costs for that work summed up. These costs were added into each CENTPLANT spreadsheet program as an input (see Appendix 5).

8.5.3 Permits and Licenses

All power plants will require some regulatory approval, so the costs of obtaining necessary permits have been factored into the total sum. Complete siting permit costs are unknown at this stage, but site application fees are known. For example, the Oregon Energy Facility Siting Council requires a $15,000 fee to submit an application for plants over 25 MW in size. Using this amount as a starting point, additional costs would include staff time to hold and attend local, state, and federal hearings; miscellaneous permit fees; and administrative/legal challenges. Therefore it has been determined that an appropriate estimate easily could be $50,000. These costs are small relative to total plant costs. And again, this cost may be modified.

8.5.4 Well Costs

Perhaps the most tenuous cost estimate is the deep well cost. Only four deep geothermal exploration holes have been drilled in the Northwest. Northwest Natural Gas with U.S. DOE support drilled a 1,830 m (6,000 ft.) well at Old Maid Flat on Mt. Hood in 1980. That hole cost approximately $1,000,000 (Geyer, 1984).

Sunedco Inc. drilled a well at the Breitenbush KGRA in 1981 to a depth of 2,457 m (8,060 ft.). While no published cost data are available on that hole, the Assessment Team sought the advice of the drilling consultant involved in that work. This same consulting firm, Columbia Geoscience Inc., also is familiar with Basin and Range production drilling.

At Meager Creek, British Columbia, three wells averaging 3,000 meters (ca 10,000 ft.) were drilled in 1981 and 1982 . Allowing for circumstances peculiar to the project and area, the cost to B.C. Hydro averaged $4.2 M per well (largely because the wells were drilled at a very steep angle) (Larkin, 1984).

The Assessment Team obtained informal opinions from Occidental Geothermal Inc., operator of the only production-size well drilled at the Medicine Lake KGRA in northern California. Their advice bears directly on our well cost estimates because that well was drilled in 1984 and the site parallels geologically the environment of Newberry Volcano.

As a final cross-check, California and Utah drilling costs from 1979 were escalated and found to be less than ours (Cassel, 1979).

Arbitrary but conservative counseled assumptions used to derive large, central plant well costs are as follows:

- Average well depth of 2,000 meters (6,500 feet);
- Production well cost is $2,000,000;
- Injection well cost is the same;
- Production well to injection well ratio is 3:2;
- Both production and injection replacement wells are included in the life cycle cost calculations;

- o Dry holes are 1 per 10 MW of capacity; and
- o Power per well is 3 MW in the Cascades, 4 MW in the Basin and Range province.

These appear to be the most conservative yet realistic well cost estimates which can be inferred from the present level of production well experience in the Pacific Northwest.

8.5.5 Bechtel Methodology

Data used for developing generic wellfield and plant cost relationships for resources 177°C (350°F) and higher, include published estimates for a number of plants that have been constructed, and cost estimates from Bechtel conceptual, preliminary, and detail designs. These data and the complete Bechtel cost report are in Appendix 5.

A reasonably large amount of data for dry steam generating facilities are available due to the extensive development at The Geysers that includes 20 generating units ranging from 11 to 135 MW (net). However, cost data available for plants using hot water resources are not nearly as extensive since construction in the United States has only recently begun on plants that use these resources. Currently, there are five operating power plants of 7 MW or more capacity in the United States using hot water resources--the 7 MW (net) binary plant at Casa Diablo (California), the 10 MW (gross) East Mesa (California) binary plant, the 11 MW (gross) flash steam plants at Brawley (California) and Salton Sea (California), and the 20 MW (net) flashed steam plant at Roosevelt Hot Springs (Utah). Three other plants, ranging in size from 9 to 47 MW (net), are under construction but are not yet operating--the 9 MW (net) flashed steam plant at Desert Peak (Nevada), the 45 MW (net) binary plant at Heber, and the 47 MW (net) flashed steam plant at Heber (California). These eight plants use hot water resources ranging from 177°C to over 260°C (350-500°F).

Approximately 118 geothermal power generating units are operating elsewhere in the world, but cost data for them have not been used in this study because of the great difficulty in obtaining, interpreting, and analyzing cost data from other countries.

Plants of the same capacity, but using hot water resources with different temperatures and different energy conversion processes, would be expected to have somewhat different costs. Therefore, cost relationships have been developed for resource conditions and energy conversion processes as indicated previously in Table 8.2. This classification makes maximum use of available cost data, and accounts for the cost effects of resources in the range of temperatures that have been exploited to date with plants having 10 MW capacity and greater.

In addition to resource temperatures and type of energy conversion process, a number of other technical characteristics may affect the cost of geothermal power plants. For example, if the hydrogen sulfide (H_2S) content of the geothermal fluids is low, there may be no need for an H_2S abatement system; on the other hand, all the power plants at The Geysers are required to have equipment for abating H_2S to meet California air quality requirements (see Chapter 5).

To account for the major technical characteristics that may affect the cost of geothermal power facilities, these characteristics are identified, and descriptions of low, probable, and high cost installations are provided for each characteristic, as shown in Table 8.3. Generic cost relationships for plants with capacity from 10 to 100 MWe (net) are provided in Chapter 7 of Appendix 5 to account for each of these situations. The "probable cost" in each case is based on the expected requirements in the study region. In many cases, resource data are not presently adequate for assessing the requirements, so the designation of "probable cost" is somewhat speculative until adequate resource data are available.

8.5.5.1 Adjustments

In addition to the characteristics discussed above, two additional factors may influence capital costs: site preparation based on terrain and the local labor supply. To account for these two factors, cost relationships are first developed for relatively flat, open terrain for sites in areas with adequate local construction labor. Adjustments to these initial cost relationships, which take into account mountainous terrain and areas with inadequate local construction labor, are then developed.

Table 8.3

TECHNICAL CHARACTERISTICS AFFECTING COST OF GEOTHERMAL POWER PROJECTS

Item	Low Cost	Probable Cost	High Cost
CAPITAL COSTS			
Power Plant			
H_2S abatement (steam and flashed steam power plants)	No H_2S abatement required	H_2S abatement costs similar to design for The Geysers	H_2S abatement costs similar to design for The Geysers
Wellfield Surface Facilities			
Production facilities (steam resource)	Low edge of estimates	Mean of estimates	Mean of estimates
Production facilities (hot water resource)	Single well island near power plant	Well islands with maximum of six wells per island	Single wells distributed uniformly over the wellfield
Reinjection facilities (steam resource)	Reinjection not required	Typical of The Geysers	Typical of The Geysers
Reinjection facilities (hot water resource)	Reinjection not required	Reinjection with no spent brine treatment; one reinjection island located one mile from the power plant	Reinjection with no spent brine treatment; reinjection wells uniformly distributed; center of reinjection field is one mile from power plant
O&M COSTS			
Power Plant			
Corrosion severity	Low end of scale in EPRI TAG (Ref. 1-1)	Low end of scale in EPRI TAG	Mid range of scale in EPRI TAG[a]
Number of units monitored by one crew of operators	6 (steam and flashed steam units) 4 (binary units)	One	One
Wellfield Surface Facilities			
Corrosion severity (steam resource)	Low end of scale in EPRI TAG	Low end of scale in EPRI TAG	Mid range of scale in EPRI TAG
Corrosion severity (hot water resource)	Midpoint of scale in EPRI TAG	Midpoint of scale in EPRI TAG	High end of scale in EPRI TAG
Number of wellfields monitored by one crew of operators	6 (steam and binary units) 4 (flashed steam units)	One	One
Reinjection pumping (hot water resource)	Not required	P = 250 psi	P = 500 psi
Production pumping (binary plant for hot water resource)	P = 250 psi	P = 250 psi	P = 500 psi

(a) The extremes of the relative cost level for the study area do not necessarily coincide with the extremes of the range in the EPRI TAG.

Site preparation involves the clearing, grubbing, grading, cutting, filling, and leveling needed to prepare a plot of 1.5 to 4 hectares (3 to 10 acres) for a geothermal power generating facility. Gently sloping land requires only a minimum of clearing, grubbing, and grading. In mountainous terrain, a level pad of the necessary size often is created by extensive cutting and filling. In some cases, the leveled area is about half cutaway hillside, and half fill. At The Geysers, the rock can usually be ripped for this earth moving, but extensive blasting is often required. With so many variables, site preparation costs are quite different from site to site. However, a generic adjustment is possible because site preparation costs usually amount to only a small percentage of the total construction cost. For this reason, large variations in cost of site preparation do not generally cause very large changes in total cost.

To quantify these effects, data from three cost estimates in Table 1.1 in Appendix 5 were used. An average of about 2 percent of total plant cost could be expected to represent a generic increase in site preparation cost compared to construction on flat land. To adjust for site preparation costs in mountainous terrain, the power plant cost should therefore be multiplied by the factor 1.02.

Site preparation costs may vary significantly from one site to another. Therefore, the adjustments suggested here may not accurately account for the site preparation costs for a particular site. However, it does point out that a typical adjustment is relatively small--only a few percentage points of total plant cost.

For wellfield surface facilities, an adjustment for added site preparation costs in mountainous terrain is probably the same low percentage of total cost.

Due to limited road access at most construction sites at The Geysers, a construction worker typically is paid for eight hours per day, but paid travel time on a company-furnished bus usually amounts to about one

hour daily. Therefore, installation labor costs in areas where this situation does not exist should be multiplied by 8/7 to adjust for this loss of productivity.

Installation labor for geothermal power plants usually accounts for 15 to 20 percent of the total cost. Therefore, the total plant cost should be multiplied by 1.02 to 1.03 to adjust for this loss of labor productivity.

The cost of wellfield surface facilities probably should be adjusted a similar percentage for a related loss of labor productivity. Some remote areas where geothermal power projects may be located are beyond a feasible commuting distance from an adequate pool of construction labor. In such situations, a construction camp would be established and operated to provide living quarters and meals for the workers.

Costs for a construction camp were estimated for plant number 19 in Table 1.1 of Appendix 5. These data were adjusted for inflation and applied to estimate the added costs for establishing and operating a construction camp. Maximum and average crew sizes were estimated as functions of plant capacity, and the duration of the construction period was taken from correlation of capacity and construction time. Since the power plant and the wellfield are often owned by different organizations, the construction camp costs for the two should be calculated separately and added to their respective cost estimates. Actually, only one construction camp probably would be established to serve both groups; however, keeping the cost estimates separate allows independent calculation of costs for the wellfield owner and the plant owner.

8.5.6 OIT Methodology

The Geo-Heat Center of the Oregon Institute of Technology (OIT) was recently under contract to the Oregon Department of Energy to assist in the evaluation of the operation of wellhead binary generators located at

Lakeview, Oregon. Part of that contract was the development of a computer program related to the production of electricity using the organic Rankine cycle to convert the energy of low temperature geothermal water (82-150°C/180-300°F). The program consisted of an engineering analysis that predicts net hourly saleable power based on key input parameters, and a generic economic analysis based on the engineering output and additional parameters. To simplify operation of the economic evaluation program, the engineering calculations were included in the second part. Nominal machine size and average net saleable power are included in the program.

Well capital costs are based on a simple, adjustable dollars per foot formula. It was felt that wells drilled for wellhead binary facilities in the Northwest will be more akin to large volume irrigation wells than steam wells. Capital costs for geothermal piping are based on geothermal water flow. Capital costs for the wellhead binary generator and the cooling tower system are based on the calculated nominal machine size. The program was intentionally designed to determine power from one well, i.e., less than 2 MW in size given the prescribed temperatures. Contingency and engineers fee (10 percent) is an added capital cost. An inflation multiplier was built into the program and capital costs are adjusted from the original date of the program, June 1983.

While this computer program can be modified to include dry hole costs, it was created without them. The program was developed from the situation at Lakeview, Oregon. No dry holes were encountered there. Any potential wellhead binary sites will need similar site advantages for economic feasibility. Even with that assumption, cost estimates still provide the relative ranking for each site.

Maintenance costs for the binary generator, cooling tower system, geothermal water piping, and well pump maintenance are based on percentages of capital cost (including proration of the contingency and engineers fee). Respective percentages for the above are: 5 percent, 3 percent, 1 percent, and 5 percent. No maintenance cost is applied to the wells. Taxes (1 percent), insurance (1/2 percent), and operating cost are based on total capital investment, excluding well costs. The program

provides for both public entities which do not pay property taxes and taxable private operators.

Annual electrical sales ($/yr) are based on average net saleable power (kW) and 7,884 hours (90 percent availability) of operation per year. Annual gross income is the sum of electrical sales ($/yr) and any annual geothermal effluent sales ($/yr). Purchased geothermal energy can be introduced into the program and treated as an operating cost, based on prices specified as an input. Similarly, effluent sold in a cascaded application can be accounted for in the existing program based on input parameters. Effluent sale is based on geothermal water flow rate and price ($/1,000 gal) as specified as an input. Annual net income is gross income less total operating cost. Simple payback is total capital investment ($) divided by annual net income ($/yr). A more precise discounted cash flow economic analysis is performed using output from this program. The analysis is discussed in further sections of this chapter.

The OIT program, as modified by the team, has considerable flexibility as is shown in Appendix 6. However, it should be remembered that this is a generic economic analysis, and does not produce as accurate an analysis as a detailed feasibility study. And although most potential electric generating sites in the region were assessed using this program, more data and experience exist for sites with estimated temperatures above 177°C (302°F).

8.5.7 Transmission Lines

Transmission line cost data were obtained from the 1983 edition of "Per Mile Cost Data For Preliminary Transmission Line Estimates" (Stone, 1983). The structure chosen as typical is a 115 kv, single circuit, Narcissus conductor, wood pole. Costs are complete, including environmental work, surveys, design, materials, construction, land, roads, and overhead. Total cost equals $119,375 per km ($191,000/mi).

Transmission line cost estimates used by the OIT methodology are for a 12 kv, single circuit, wood pole.

8.5.8 Application

The intent of applying these methodologies is to estimate current (September 1984) installed capital costs and first year operating costs. Capital and O&M costs for each high temperature site are derived from applying the modified Bechtel and OIT methodologies, as appropriate, to site specific inputs. As noted earlier, resource temperature determines which model to use. These development costs can then be used in any desired economic forecasting model.

Both methodologies' formulas were loaded onto a LOTUS 123 (TM) spreadsheet program. These simple personal computer programs calculate cost outputs based on resource, plant size, adjustment factors, and other inputs as determined in the two modified methodologies. Cost estimates can be made for plants 10 to 100 MW (net) in size using the modified Bechtel methodology, called CENTPLANT. Using the modified OIT methodology called WELLHEAD, yields cost estimates for plants under 2 MW (net) in size, although the program can accommodate more wells and subsequently more capacity. Appendices 5 and 6 contain program summaries, formula listings, and documentation for the CENTPLANT and WELLHEAD methodologies, respectively.

8.5.9 Summary

Of the original 100 BPA-area sites, 19 sites with most likely temperatures above 177°C (350°F) were selected for analysis using the Bechtel methodology. Cost estimates derived from the Bechtel methodology provide two things: a relative ranking of sites, and reasonably accurate cost estimates of a 50 MW power plant at each site. Table 8.4 provides estimated costs for the 19 applicable sites. The costs calculated include the following:

- Remaining assessment work,
- Permits and licenses,
- Production and injection wells,
- Dry holes,
- Wellfield capital costs with adjustments,
- Wellfield O & M costs,
- Power plant capital costs with adjustments,

- o Power plant O & M costs,
- o Transmission line costs, and
- o 20 percent contingency

The modified OIT methodology was applied to all but 10 of the remaining 81 sites. For these ten sites, insufficient data were available. Cost estimates derived from this methodology provide two things: a relative ranking of each site, and reasonably accurate cost estimates of .2 - 2 MW wellhead binary power plants at each site. These estimates are liberal in that dry hole costs are not included. Rather, it is assumed that all remaining assessment work will be completed at the highest temperature sites, while moderate temperature sites will proceed with the production well constituting the assessment work. Results are shown in Table 8.5.

TABLE 8.4. - CENTPLANT Cost Estimates

OREGON

Site	Conversion Process[1]	Estimated Capital Cost ($/Net KW)[2]	Estimated O & M Cost ($/KW/YR)
Newberry Volcano	SF	2,899	49
Wart Peak Caldera	SF	3,055	62
Glass Butte	SF	3,075	63
Cappy-Burn Butte	SF	3,232	62
Mickey HS	SF	3,240	65
Bearwallow Butte	SF	3,369	61
Melvin/3-Creek Buttes	SF	3,379	61
Vale HS	B	3,524	81
Klamath Falls area	DF	3,541	87
Olene Gap HS	DF	3,544	87
Klamath Hills area	DF	3,565	87
Neal HS	DF	3,580	85
Crump HS	DF	3,588	88
Borax Lake HS	DF	3,688	90
Alvord HS	DF	3,754	90
Trout Creek area	DF	3,774	92
Crater Lake area	DF	3,951	89
Generic High Cascades	DF	4,014	89
Mt. McLoughlin	DF	4,066	90

Subtotal: 19

1 SF = single flash, DF = double flash, B = binary.

2 Costs are complete for a 50 MW net field and plant. Power plant costs alone are approximately one third those shown. See Appendix 5 for documentation.

TABLE 8.5 - WELLHEAD Cost Estimates

Site	Estimated Capital Cost ($/Net KW)[1]	Estimated O & M Cost ($/KW/YR)	Net Plant Size (KW)[2]
Cove & Crane Cr., ID	2,099	91	1,810
Big Creek HS, ID	2,177	93	1,679
Vulcan HS, ID	2,215	96	1,706
Boulder HS, MT	2,499	143	1,155
Raft River area, ID	2,621	117	1,989
Jackson HS, MT	2,891	166	925
Ennis, MT	2,963	158	1,006
Lakeview area, OR	3,007	130	1,249
Summer Lake HS, OR	3,101	134	1,209
Gregson HS, MT	3,174	184	762
Hallinan Springs, OR	3,181	137	1,173
Broadwater HS, MT	3,213	185	748
Fischer HS, OR	3,232	139	1,151
Barry Ranch HS, OR	3,241	140	1,148
Deer Creek HS, ID	3,236	140	1,089
Magic HS, ID	3,466	330	1,030
Roystone HS, ID	3,543	151	958
Norris HS, MT	3,710	212	547
Baker HS, WA	3,727	141	1,086
Owl Creek HS, ID	3,760	165	932
Mt. Hood, OR	3,899	147	1,144
White Arrow, ID	4,247	181	764
Indian Creek HS, ID	4,365	184	729
Squaw Creek HS, ID	4,423	183	743
Crane HS, OR	4,502	187	724
Luce HS, OR	4,682	190	667
Sharkey HS, ID	4,718	196	646
Bonneville HS, ID	4,916	204	612
Belknap HS, OR	4,916	200	601
Battle Creek HS, ID	4,933	199	624
Little Valley area, OR	5,025	200	597
O.J. Thomas well, OR	5,035	207	627
Umpqua HS, OR	5,132	187	711
Marysville well, MT	5,471	281	532
Beulah HS, OR	5,595	199	624
Cabarton HS, ID	5,680	222	474
Riggins HS, ID	5,981	232	437
Maple Grove HS, ID	6,012	230	431
Barron's HS, ID	6,079	232	422
Murphy HS, ID	6,079	232	422
Krigbaum HS, ID	6,103	232	420
Blue Mountain HS, OR	6,179	212	538
Weberg HS, OR	6,179	212	538
Breitenbush HS, OR	6,232	212	528
Boiling HS, ID	6,672	245	363
Foley HS, OR	6,677	244	362
Ben Meek Well, ID	7,232	252	334

Site	Estimated Capital Cost ($/Net KW)[1]	Estimated O & M Cost ($/KW/YR)	Net Plant Size (KW)[2]
Rustler Peak, OR	7,254	234	422
Latty HS, ID	7,288	256	314
Bigelow HS, OR	7,351	258	310
Guyer Hot Springs, ID	7,379	259	308
Sunbeam HS, ID	7,636	265	291
Cougar Peak, OR	7,704	240	385
Devils Garden area, OR	7,704	240	385
Diamond Craters, OR	7,704	240	385
Four Craters area, OR	7,704	240	385
Squaw Ridge area, OR	7,704	240	385
China Hat/East Butte, OR	7,803	241	377
Frederick Butte, OR	7,803	241	377
Quartz Mountain, OR	7,803	241	377
Austin HS, OR	8,165	245	351
Jackies Butte Field, OR	8,242	247	347
Jordan Craters area, OR	8,242	247	347
McCredie HS, OR	8,710	255	321
Cropp HS, OR	9,084	261	302
Medical HS, OR	9,084	261	302
Kahneeta HS, OR	9,216	262	296
Mitchell Butte HS, OR	9,585	294	217
Worswick HS, ID	9,785	303	200
McDermitt area, OR	10,639	311	187
Wall Creek WS, OR	11,129	289	227
Big Southern Butte, ID[3]	--	--	--
Blackfoot Lava Field, ID[3]	--	--	--
Island Park Caldera, ID[3]	--	--	--
Mt. Adams, WA[3]	--	--	--
Mt. Baker, WA[3]	--	--	--
Puny Creek, WA[3]	--	--	--
Rexburg Caldera, ID[3]	--	--	--
Shukash Basin, OR[3]	--	--	--
Silver Star, MT[3]	--	--	--
White Licks HS, ID[3]	--	--	--

Total Sites: 81

1 Costs include well, piping, and plant.
2 Parasitic loads vary, hence net power is presented here. See Appendix 6 for documentation.
3 Insufficient data available.

8.6 Levelized Cost of Geothermal Power

8.6.1 Levelized Cost Procedure

The Pacific Northwest Geothermal Assessment Team uses a constant dollar levelized cost procedure to determine the costs of produced or

conserved electricity from surveyed resources. This method is strictly based on the BPA costing procedures for consistently comparing alternative resources (BPA, 1984). Although such a method does yield important characteristics for the resource, it cannot take into account less tangible factors in the economic process such as the quality of the resource, reliability and availability, or other factors outside the scope of the accounting process (such as environmental concerns). Regardless, levelized costs probably provide the most compelling argument for resource development and frequently are used for comparisons.

Determination of the cost of produced or conserved power from a resource is made more difficult by the fact that inflation distorts cost decisions since it makes it appear as if a resource acquired at a later time is more expensive than one acquired in 1984. In actuality, the decision to build now or later may have no effect on the budget. Also, it is difficult to compare the cost of different projects because expenses may occur at different times. These costs include construction, operation and maintenance, interest, non-recurring capital and fuel costs. Based on single party wellfield/plant ownership a geothermal project has a very large capital cost associated with the drilling of wells and building of the plant, but the "fuel" is very inexpensive there after. On the other hand, a gas combustion turbine may be relatively inexpensive to build, but fuel costs will be quite high over the long run.

The levelized cost method estimates project costs through the use of "constant 1984" dollars. Many "cost streams" are uneven as they contain different applicable inflation rates, and must be converted into equivalent annual cost payments so that the present value of the payments is equal to the original uneven costs. The nominal cost stream is converted into constant 1984 dollars which are then discounted back to a present value at the resource's start up date. The discount rate used is quite important to this process. The recommended BPA value of 3 percent is used in all the analyses. After being discounted, the present value is amortized back over the project life by the discount rate. The resulting annual cost is then divided by the project energy output or offset to find the levelized cost per kilowatt hour. In this fashion all resources may be evaluated on a consistent basis.

The generalized form of the levelized cost equation is:

$$LCe = \frac{CRF * \sum_{n=1}^{PL} \frac{Cn}{(1+D)^N}}{Eo}$$

Where:

LCe = the levelized first year cost (mills/kilowatt hour) of electric power production or offset.

CRF = Capital Recovery Factor (annuity of present value)

PL = the project life (years)

D = real discount rate (nominal/inflation rate)

Cn = sum of costs in year "n" (capital, environmental, operating, returns to sponsor, and other costs in constant dollars).

Eo = average annual energy output (kWh)

To determine the levelized cost, parameters must be specified for use with this procedure. This takes two forms; the economic data and the project specific data. For the purpose of a consistent evaluation process, all economic parameters and some of the project specification have been kept constant through the entire evaluation procedure: (Tables 8.6 and 8.7)

TABLE 8.6 - Economic Parameters for Study

Inflation Rate (IR)	6 percent
Real Escalation Rate (RE)	1.3 percent
Real Discount Rate (D)	3 percent
Finance Rate (I)	13 percent
Construction Finance Rate (FI)	13 percent
Cost Price Level (CP)	1984
Year on Line (YOL)	1990
Physical Life (PL)	30 years
Plant Size (MW)	50 MW
Capacity Factor (CF)	80 percent
Capital Cost per kWh (CC)	Varies
Variable Cost (V)	Varies
Fixed Costs (F)	Varies
Cash Flow During Construction (CAn)	

Table 8.7 - Geothermal Project Data

Year	percent of Direct Cost
1	20 percent
2	30 percent
3	50 percent

8.6.1.1 Economic Assumptions

A number of economic parameters were specified in the study that have a large bearing on the estimated levelized cost of electricity. In general, we have taken the numbers that B.P.A. and Kaiser (Kaiser Engineers Power Corporation, 1983) have used in their studies of geothermal potential. This insures a comparative basis for our assessment. Furthermore, we have opted for conservative estimates where the actual values are not known with precision.

Our assessment includes a 3 percent real discount rate, a six percent inflation rate and a 13 percent finance rate. The discount and inflation rates were taken directly from BPA (1984) although the finance rate was increased from 12 percent to 13 percent to more appropriately account for the higher costs of capital typically being incurred in recent time. We chose

a 1984 cost price level for consistency in the discounting procedure. A 1.3 percent real operation and maintenance cost escalation rate and a project life of 30 years was taken directly from the Kaiser study. The project life has a very large effect on the levelized cost and in retrospect we believe that a 25 year horizon would be more reflective of the conservatisms adopted in the study elsewhere. In any case, such a change is studied in sensitivity analysis later in this chapter (section 8.6.7).

We assumed that a geothermal project would take six years from design to turn-key and that the actual plant construction would take place over a three year period.

8.6.1.2 Project Related Parameters

We have assumed different assumptions on the project size and development scenario than those used in the Kaiser study. We chose a 50 MW plant as the smallest plant size that a geothermal developer would seriously entertain as a viable economic investment. This is due to the large economies of scale that are available in geothermal development.

Unlike the Kaiser study, we have assumed that a single developer or utility consortium both developes the well field and the plant to minimize production costs. This avoids the expensive levelized costs of steam that a well field developer will typically charge a utility. We believe that although our approach is not the only way of modeling this relationship. It is however, a viable increasingly practical and, more cost effective one in terms of generating low cost electricity.

To be conservative on a critical issue, we have chosen a 80 percent capacity factor for our plant as opposed to an 84 percent rate chosen by the Kaiser study. As mentioned previously, a $2 million cost per well is assessed with a 25 percent chance of dry holes and a 50 percent well replacements over the life of the project. All of these estimates are conservative. Finally, we have added a 20 percent contingency on all wellfield and plant related costs in the assessment.

8.6.2 First Year Costs and Produced Power

In the following calculations, the cost components are estimated as well as the power produced from the facility. Costs consist of the total installed cost, and the variable, fixed, and operation and maintenance cost components. The power produced is a function of the plant size and average availability:

The annual electrical energy produced from the geothermal plant is:

$$E = MW * CF * 1000\ kW/MW \times 8760\ hrs/yr$$

The total installed cost of the plant is:

$$TCC = CC * MW * 1000\ kW/MW$$

The value CC is determined from the cost relationships from the Bechtel study and estimated cost for wells for the plant (Bechtel, 1984). The annual variable cost for plant operation is:

$$VA = V * E$$

The annual fixed cost component is:

$$FC = F * MW * 1000\ kW/MW$$

The annual operation and maintenance costs are:

$$OM = VA + FC$$

8.6.3 Estimating Nominal and Constant Dollar Cost Streams

It is then necessary to portray the operation and maintenance costs stream in nominal terms. This is done for each year beginning with 1984. The plant operation is assumed to occur in year seven (1990).

$$VEn = OM * ((1+I) * (1 + RE))^N$$

Where:

VEn = nominal O&M costs in year "N"

The capital cost stream is computed for the construction years:

$$TEn = TCC * CAn * ((1+I) * (1+RE))^{N}$$

The total direct cost (TDC) is simply the sum of TEn. Interest during construction is:

$$IDC = (TE) * ((1+ CIR)^{(CT-N + .5)} -1)$$

The annual mortgage payment is:

$$MO = (TDC + IDC) * CRF(PL)$$

The annual total nominal cost stream is:

$$CSTn = MOn + VEn$$

It is then necessary to convert the total nominal cost stream into constant 1984 dollars:

$$CNn = CST * (1/ (1 + I)^{N}$$

The total constant dollars is then the sum of the constant dollar cost stream (CNn).

8.6.4 Calculating Levelized Present Value of the Cost Stream

The present value of the constant 1984 dollars cost stream is:

$$PV = \sum_{N=1}^{PL} (CDn / (1 + D)^{N})$$

The levelized cost of the present value of the cost stream is the final result of the computations. The levelized cost of power is then obtained by dividing by the annual energy produced or offset (E).

$$LC = \frac{CRF * PV}{E}$$

"LC" is the levelized cost of power produced or offset and may be compared against another geothermal resource or competing non-renewable resource to determine their relative economic attractiveness.

8.6.5 Application

Obviously, from the foregoing procedure, the initial cost of a geothermal plant will have a major effect on the levelized cost. The costs of geothermal plants vary widely depending upon the available water temperatures and the degree of contaminants in the geothermal fluids.

For our base case scenario, we assumed a 50 MW plant using 258°C (500°F) feedwater with hydrogen sulfide removal. For this level of production, we assumed 17 production wells and 11 injection wells for Cascades sites, and 13 production and 8 injection wells for other sites. Wells were estimated to cost $2 million each, assuming a 2,000 meter drilling depth and 3 MW per well for Cascades sites and 4 MW per well for others. It is noteworthy that The Geysers experience has been up to 7 MW per well. In addition, we assumed that half of all production wells and 25 percent of all injection wells will be replaced ove the project life. This also seems very conservative, given current geothermal power production experience. These costs were factored into the method as irregular occurring operation and maintenance costs.

An example of the CENTPLANT cost estimation format is shown in Figure 8.10 Based on Bechtel advice, all O&M costs are assumed to be fixed. The total capital cost per kWh is estimated to be $1,398 for the example.

SITE: Newberry Volcano

Input

Resource Temperature	258°C	a1 =	2.400
Net Capacity	50 MW	b1 =	0.699
Technology (SF, DF, B)	SF	c1 =	0.030
Terrain Labor Factor (Y=1, N=0)	0	a2 =	0.178
Terrain Site Prep (Y=1, N=0)	1	b2 =	1.000
Construction Camp (Y=1, N=0)	0	a3 =	0.470
Plant O&M: Low, Prob., or High	P	b3 =	0.700
Production Equip.: L, P, H	P	c2 =	0.060
Reinjection Equip.: L, P, H	P		
Well O&M: L, P, H	P		
Electricity Cost	2.15 ¢/kWh		
Interest Rate	13.5 percent		
Distance to Trans. Lines	12 km		

Output (in $ million)

Remaining Assessment Work	2.985	(Input)
Permits/Licenses	0.050	(Input)
Production & Injection Wells	55.600	(Input)
Power Plant Capital Costs		
Power Plant	36.965	
H_2S Abatement	4.436	
Terrain Labor Adj.	0.000	
Terrain Site Prep. Adj.	0.828	
Construction Camp	0.000	
Subtotal	42.229	
Plant IDC	5.643	
Total Plant Capital Costs	47.872	
Plant O&M Costs	2.242	
Wellfield Capital Costs		
Production Equipment	8.900	
Reinjection Equipment	7.267	
Terrain Labor adj.	0.000	
Terrain Site Prep. Adj.	0.323	
Construction Camp	0.000	
Subtotal	16.491	
Wellfield IDC	2.204	
Total Wellfield Costs	18.694	
Wellfield O&M Costs	0.198	
Transmission Line Costs	1.433	(BPA 115 kv $s)
Total Capital Costs	126.634	
($ per New kW)	$2,532.69	
Total O&M Costs	2.440	
($ per Net kW)	$ 48.80	

FIGURE 8.10 - CENTPLANT Cost Estimate Sheet

The LOTUS 123 (TM) spreadsheet program was used to create a calculation sequence that performs the above procedure. It uses all previously described algorithms, and is fast and flexible in use. All input variables are easily entered for parametric study. It performs the levelized cost estimate in about 30 seconds.

The LOTUS 123 (TM) spreadsheet display cannot be entirely reproduced here, since the six columns extend well beyond the 80 column margin that can be printed. Consequently, only analysis results are presented.

8.6.6 Comparison of Results with the Kaiser Study

Figure 8.11 presents an analysis of a hypothetical 10 MW electrical power plant using 258°C (500°F) feedwater at Newberry Caldera in Oregon. Using the Bechtel cost estimates, 2 million dollars per 4 MW well, and otherwise incorporating all the economic assumptions made by the Kaiser Study, we estimate the cost of electricity generation to be 60.39 Mills/kWh. Note that plant capacity factor was held constant at 84 percent so that the results are comparable.

To be sure that our levelization routine was operating properly, we entered the exact project data from the Kaiser study into our economic model. We estimated a levelized cost of 74.67 mills/kWh (Figure 8.12) as opposed to the 73 mills/kWh reported in the Kaiser study (Table 1-1 for the Geo-3 resource, Kaiser Engineers Power Corp., 1983). The two mill difference between the two estimates are due to varying assumptions on the construction cost schedules. Thus, we have verified our model of the levelized cost procedure.

The assumptions used in our study resulted overall in a levelized cost some 14 mills/kWh lower than estimated in the Kaiser report. Given the competition between resources for a market share of future generation, this difference (a 20 percent) is quite significant. It will be noted that the differences arise from the way in which Kaiser estimated the cost of steam for geothermal plant operation. This is the variable cost term in their evaluation. Kaiser assumed that an independent well field developer would supply steam to a utility based on California experience. The sales price of

steam is then tied to the cost of energy in that state. However, this may not be a reasonable indicator of conditions in the Pacific Northwest. We have explicitly estimated all the costs of well field development and assumed a concerted effort on the part of a single firm to develop the wells, build the plant and market the power. This results in a cost minimizing strategy for power generation.

BPA Cost Methodology for Resource Assessment Assumptions

Assumptions	Data	
Real Discount Rate	3 percent	**GEOTHERMAL ASSESSMENT**
Finance Rate	12 percent	**GROUP**
Fixed Cost/kW	$ 80	
Capital Cost/kW	$ 4,225	
Replacement Well Cost	$2,000,000	Newberry Volcano
O&M Escalation Rate	1.3 percent	
Plant Size (MW)	10 MW	**Levelized Cost**
Variable O&M Costs	$ 0.0000	**60.39**
Physical Life	30 years	**Mills/kWh**
Construction Cost/yr 1	20 percent	
Construction Cost/yr 2	30 percent	
Construction Cost/yr 3	50 percent	
Capacity Factor	84 percent	One Dry Well 2 Replaced
Inflation Rate	6 percent	20 Percent Capital Cost
Year On-Line	1990	Contingency
Annual Electricity	73,584,000 kWh	
Total Plant Capital Cost	$42,250,000	
Variable Cost	$ 0	
Fixed Cost	$ 800,000	
Annual Total O&M Cost	$ 800,000	
Capital Recovery Factor	.1241	
Discount CRF	.0510	

Construction Costs	Interest	Year
$11,233,574	$3,679,357	1987
$18,093,581	$3,352,679	1988
$32,380,875	$1,887,822	1989

FIGURE 8.11 - 10 MW Geothermal Single Flash Levelized Cost Assessment Team Assumptions

Assumptions	Data	
Real Discount Rate	3 percent	**KAISER 10 MW**
Finance Rate	12 percent	**ASSUMPTIONS**
Fixed Cost/kW	$ 44	
Capital Cost/kW	$ 1,709	
Replacement Well Cost	$ 0	Newberry Volcano
O&M Escalation Rate	1.3 percent	
Plant Size (MW)	10 MW	**Levelized Cost**
Variable O&M Costs	$ .0360	**74.67**
Physical Life	30 years	**Mills/kWh**
Construction Cost/yr 1	20 percent	
Construction Cost/yr 2	30 percent	
Construction Cost/yr 3	50 percent	
Capacity Factor	84 percent	
Inflation Rate	6 percent	
Year On-Line	1990	
Annual Electricity	73,584,000 kWh	
Total Plant Capital Cost	$17,090,000	
Variable Cost	$2,649,000	
Fixed Cost	$ 439,000	
Annual Total O&M Cost	$3,088,024	
Capital Recovery Factor	.1241	
Discount CRF	.0510	

Construction Costs	Interest	Year
$4,543,947	$1,488,289	1987
$7,318,800	$1,356,149	1988
$13,097,968	$ 763,618	1989

FIGURE 8.12 - 10 MW Geothermal Single Flash Levelized Cost
Kaiser Study Assumptions

From the Bechtel study, it is evident that significant economies of scale are available from geothermal power production. Figure 8.13 shows the spreadsheet analysis for a 50 MW plant at Newberry, versus the 10MW unit previously examined. The levelized cost of power falls to 50.45 mills/kWh in the larger unit. This represents a practical size for geothermal plants of this type, and a representative estimate of the levelized cost of geothermal electricity with a single flash technology.

8.6.7 Sensitivity and Uncertainty in the Estimates

In all cases, the present study has made use of conservative estimates. The numbers presented here are likely to be more realistic for the present Northwest situation than their Kaiser counterparts because that study used an estimated cost of steam to a utility, rather than the actual cost of producing the steam as estimated in this study. Furthermore, a 20 percent contingency fee has been added to the estimated direct capital costs from the Bechtel costs, and the $2 million per well is higher than the $1.5 million cost commonly quoted by geothermal power producers. This is shown graphically in Figure 8.14 where Edelstein, Blair and Amundsen (1979) estimated about $1.2 million for such a well drilled in igneous rocks in 1979. Even assuming an implicit price deflator of 1.37 for the period fourth-quarter 1979 to 1984, this translates to $1.64 million per well in 1984 dollars.

BPA Cost Methodology for Resource Assessment

Assumptions	Data	
Real Discount Rate	3 percent	Includes 4 Dry Wells
Finance Rate	13 percent	11 Wells Replaced
Fixed Cost/kW	50	
Capital Cost/kW	$ 3,231	
Replacement Well Cost	$2,000,000	Newberry Volcano
O&M Escalation Rate	1.3%	
Plant Size (MW)	50 MW	**Levelized Cost**
Variable O&M Costs	$ 0.0000$.0360	**50.54**
Physical Life	30 years	**Mills/kWh**
Construction Cost/yr 1	20%	
Construction Cost/yr 2	30%	20 percent Capital Cost
Construction Cost/yr 3	50%	Contingency
Capacity Factor	80%	
Inflation Rate	6%	
Year On-Line	1990	
Annual Electricity	350,400,000 kWh	
Total Plant Capital Cost	$161,550,000	
Variable Cost	$ 0	
Fixed Cost	$2,500,000	
Annual Total O&M Cost	$2,500,000	
Capital Recovery Factor	.1334	
Discount CRF	.0510	

Construction Costs	Interest	Year
$42,953,465	$15,349,993	1987
$69,183,857	$13,920,240	1988
$123,813,737	$7,802,071	1989

FIGURE 8.13 - 50 MW Geothermal Single Flash Levelized Cost

The power produced from each well is assumed to be 3 or 4 MW versus the 5 to 10 MW found elsewhere. Twenty-five percent of the drilled wells are assumed to be dry holes and 50 percent of the production wells are slated for replacement over the project life.

It should be noted that over 60 percent of total geothermal power production costs are due to expenses associated with the well field. Based on this fact, we surmise that the cost of geothermal power is very sensitive to the well field drilling certainty and well production longevity. These risks should be given serious scrutiny in any specific project evaluation.

As a generic study of project uncertainties, we have examined changes in levelized costs associated with key assumptions in the analysis. The Newberry Caldera case was used for reference. Tests included drilling confidence level, average capacity factor, replacement well rate and project life. The changes in levelized costs are summarized in Tables 8.8, through 8.11:

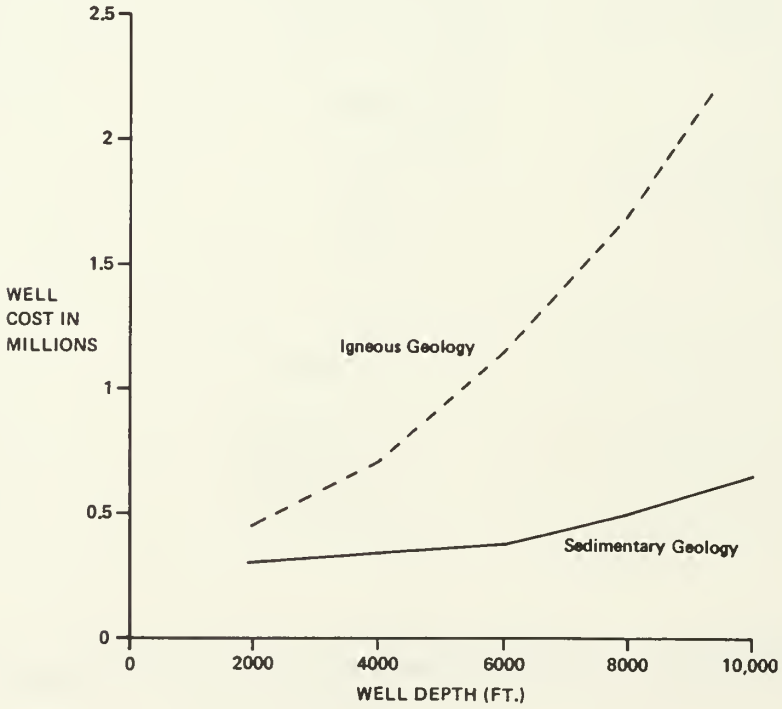


Figure 8.14 - Sensitivity to geothermal deep well costs.

TABLE 8.8 - Sensitivity to Drilling Confidence Level

Probability of Finding Suitable Fluids	Levelized Cost Mills/kWh
100%	46.64
90	48.42
80	50.62
70	53.42
60	57.20
50	62.47
40	70.38
30	83.57
20	109.95
10	189.09

TABLE 8.9 - Sensitivity to the Percentage of Wells Replaced Over Project Life

Percent Replaced	Levelized Cost Mills/kWh
0	47.95
20	49.22
40	50.48
60	51.74
80	53.00
100	54.26
150	57.42
200	60.57

TABLE 8.10 - Sensitivity to Plant Capacity Factor

Capacity Factor Percent	Levelized Cost Mills/kWh
50%	80.72
60	67.26
70	57.65
80	50.45
90	44.84

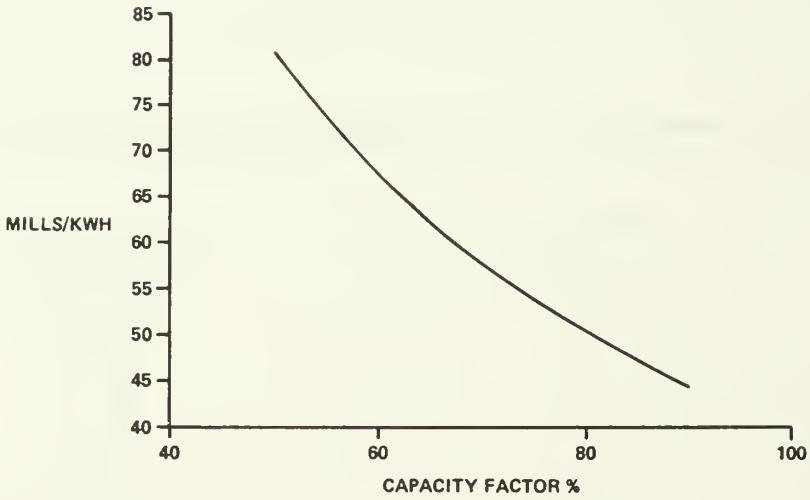


Figure 8.15 - Sensitivity to capacity factor.

Generally, we have observed that levelized cost is most sensitive to expected project life, and the long term plant capacity factor. Costs are relatively insensitive to well replacement rate and moderately sensitive to the probability of finding suitable fluids on each drilling attempt. However, this factor becomes critical as the confidence level goes below 50 percent.

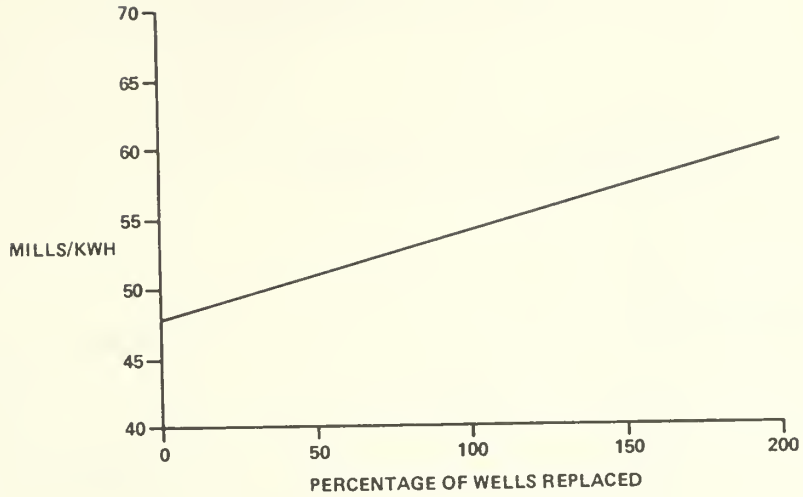


Figure 8.16 - Sensitivity to well replacement rate.

TABLE 8.11 - Sensitivity to Project Life

Years	Levelized Cost Mills/kWh
15	92.88
20	69.84
25	57.76
30	50.45

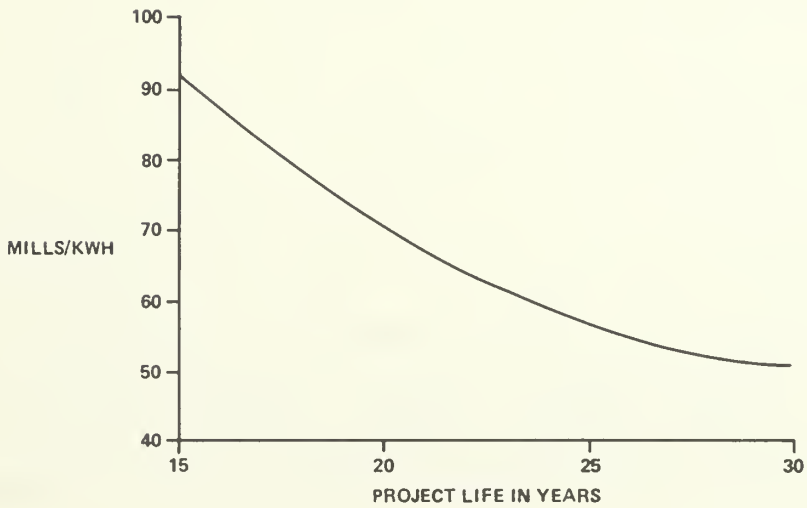


Figure 8.17 - Sensitivity to project life.

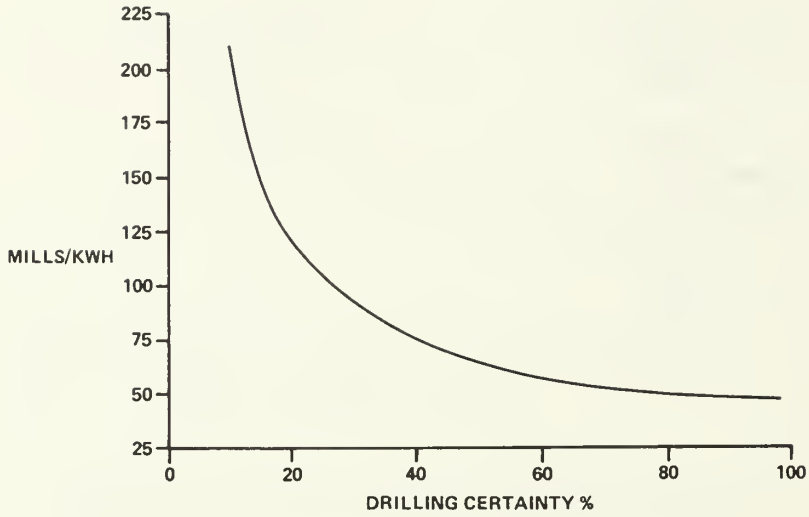


Figure 8.18 - Sensitivity to drilling risk.

8.6.8. Sensitivity of Failed Lease Plays on Project Cost

A sensitivity study also examined the added cost associated with the exploration of two lease blocks which did not reach development. This is an added expense to a successful project which comes to fruition as a third lease play. These were analyzed so that they were identical to one time "dry holes" with a fixed cost for the lease plays. The Newberry Volcano reference case was used as a basis for the sensitivity. Six scenarios were examined.

The results of the study showed this to be a non-critical variable in the overall assessment (Figure 8.19). The worst case, scenario No. 6 yielded a maximum of three mills/kWh increase over the reference result. The minimal increase which can be attributed to the "risk" associated with exploration does not appear to justify the cost differential noted previously in the comparison of single field/plant development and ownership as opposed to two party arrangements where a utility purchases steam from field developers. And although this appears to add considerable weight to our argument for single party development of projects, joint ventures between field developers and plant operators could also be expected to reduce the overall cost of electricity, however the percent reduction would be highly dependent upon the specific arrangement. The analysis of such arrangements and the sensitivity to cost is well beyond the scope of the present study.

TABLE 8.12 - Sensitivity to Failed Lease Plays

	Scenario	Additional Exploration Cost	Mills kWh
	BASE CASE		50.25
1.	Base Case + One Lease Play + 1 Deep Well	$ 5,009,100	50.73
2.	Base Case + One Lease Play + 2 Deep Wells	$ 7,009,100	51.20
3.	Base Case + One Lease Play + 3 Deep Wells	$ 9,009,100	51.67
4.	Base Case + One Lease Play + 4 Deep Wells	$11,009,100	52.15
5.	Base Case + Two Lease Plays + 5 Deep Wells	$16,018,200	52.62
6.	Base Case + Two Lease Plays + 6 Deep Wells	$18,018,200	53.10

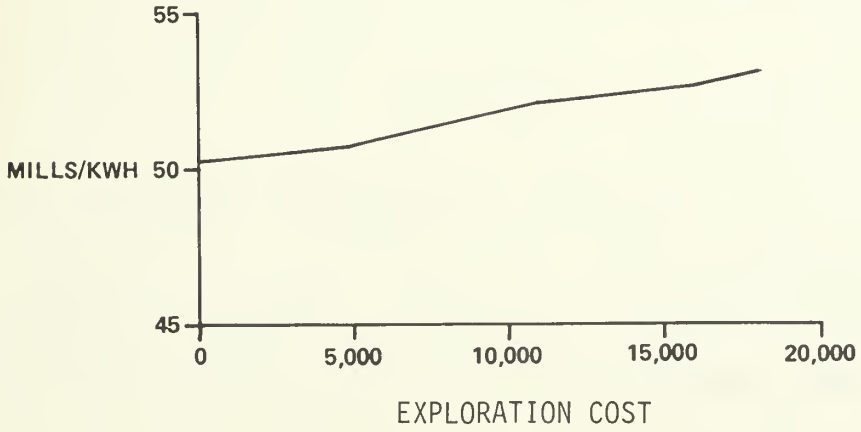


Figure 8.19 - Sensitivity to failed lease plays.

8.7 Conclusions

The objective of high temperature site characterization work has been to first develop complete, generic capital and O&M costs for the range of plant capacities from less than 1 MW to 100 MW net. Cost data were derived from a variety of sources familiar with actual costs of existing wells, plants, and facilities. Bechtel National, Inc., and the Oregon Institute of Technology Geo Heat Center furnished cost information. This data was then modified by the Assessment Team and used for ranking various geothermal resource prospects. Realistic estimates for generic costs of facilities were developed for use in economic screening of all potential sites. A major accomplishment has been achievement of easy modification of capital cost inputs. This enables testing of specific variables for impact upon overall costs.

Of the original 100 sites, estimates for 19 sites with most likely temperatures above 177°C (350°F) were made using the modified Bechtel methodology. Cost estimates provide two things: a relative economic ranking of each site, and a reasonably accurate cost estimate of a 50 MW power plant at each site. Relative cost ranking is achieved through uniform assumptions applied at each site. While theoretical potential varies according to site, data are insufficient to predict individual plant sizes. Therefore, a relative comparison is achieved here, and the ability to estimate different plant size costs is included. Complete cost estimates include the following:

- Remaining assessment work
- Permits and licenses
- Production and injection wells
- Dry holes
- Wellfield capital costs with adjustments
- Wellfield O&M costs
- Single flash, double flash & binary power plant capital costs with adjustments
- Power plant O&M costs
- Transmission line costs
- 20 percent contingency

For the remaining 81 sites, a modified OIT methodology was applied to all but 10 sites, where sufficient data were unavailable. Cost estimates derived from this methodology provided two things: a relative ranking of each site, and reasonably accurate cost estimates of .2 - 2 MW wellhead binary power plants at each site. Again, relative cost ranking has been achieved through uniform assumptions applied at each site. Unlike the 19 sites with higher estimated temperatures, these sites had varying power potentials, given uniform flow assumptions. Temperature and level of data were the primary factors controlling cost at these sites.

Capital costs include well, piping, and plant costs, but do not include remaining assessment work, dry holes, and transmission line costs. These costs are excluded because of their impact on project feasibility. Significant costs in **any** of these categories probably would kill a project.

The BPA levelized cost procedure has been successfully adapted for analysis by the Pacific Northwest Geothermal Assessment Project. It compares favorably with the Kaiser estimates of a single flash geothermal resource levelized costs when using Kaiser's figures.

The study has closely scrutinized assumptions going into levelized cost estimates, and based on our best data have estimated a similar geothermal resource to have a levelized costs substantially lower than Kaiser estimates for a 10 MW facility. Our estimate is approximately 60 mills/kWh versus 74 for the Kaiser assumptions. Most of this difference is due to the fact that Kaiser expenses fuel costs on the basis of California utility experience where the price of steam is tied to external indicators which typically experience escalation over time, while the team chose to capitalize both field and plant costs. The manner in which fuel costs are treated appears to be the single most sensitive factor affecting the levelized cost of energy and is a direct reflection of the difference between single party field/plant development and two party arrangements where a utility purchases steam from a field developer. This cost difference is usually attributed to the need for a high rate of return for the field developer because of the risks incurred in exploration. However, this appears to be an over

simplification in that according to our analysis, exploration risk is one of the least sensitive cost variables examined. If such cost saving are achievable through single party development where field development costs can be capitalized, then it should also be possible to achieve a portion of these savings through joint ventures. How such arrangements should be structured or the magnitude of the cost savings which could be realized through such arrangements is unfortunately beyond the scope of this study.

In addition to the cost savings which can be achieved through single party development, significant cost savings can be achieved through economies of scale. In fact the levelized cost for a 50 MW plant was determined to be approximately 50 mills/kWh as opposed to the CA 60 mills/kWh for a 10 MW plant.

The argument for single party development is all the more compelling because this study makes conservative assumptions for frequency of dry wells and well replacement. An overall 20 percent contingency charge, assessed on all direct project costs, has insured realistic cost estimates. A sensitivity analysis of uncertain assumptions in geothermal project assessment has found that levelized costs are sensitive to project life, long term capacity factors, and moderately sensitive to drilling confidence levels.

It can be seen that the primary attribute of geothermal resources, temperature, directly affects cost estimates. Expressed simply, the more heat there is to begin with, the more energy can be developed per dollar invested (all other factors being equal). At the top of both cost estimates generally are the highest temperature sites. Sites on the highest temperature list also frequently have greater total potential, although this is not always the case.

This portion of the overall assessment serves several purposes:

- It lists and evaluates all known sites in the region on a uniform basis, this evaluation included all sites with a reasonable resource potential;

- It highlights sites with significant **potential** for additional investigation;

- It indicates comparable development costs and expectations;

- It itemizes major cost items in feasibility analyses; and

- It provides a framework for systematic addition and use of resource data as it becomes available.

Overall, this effort provides a reference for planning and evaluating specific development proposals, as well as further resource assessment. This work also serves as a "primer" for non-industry personnel interested in geothermal power generation.

CHAPTER 9

Direct Utilization Site Analysis

9.0 DIRECT UTILIZATION SITE ANALYSIS

9.1 Introduction

The objective of this portion of the study is to systematically evaluate and characterize geothermal sites within the BPA marketing area for direct utilization. Existing information in records and files was used to determine the electrical offset potential of individual sites as well as the cost of providing geothermal energy for district heating.

Initially, 1,265 sites were identified as potential electrical generation or direct use sites. For the purpose of this study, a direct use site is defined as a town or end-user with significant electrical offset potential which can be met through the use of geothermal district heating.

Three screens were used to select direct utilization sites in the BPA service region and they are as follows:

1. Resources with fluid temperatures greater than 10°C above the mean ambient air temperature.

2. Sites outside of environmentally sensitive areas such as National Parks, National Monuments, and designated Wilderness Areas.

3. Sites within distance to resource/population criteria:

Population	Distance
1 - 100	Resource on site
101 - 1,000	Within 2 km (1.2 miles)
1,001 - 10,000	Within 8 km (4.8 miles)
10,001 - 100,000	Within 20 km (12 miles)
100,001+	Within 40 km (24 miles)

After the screens were applied, 145 remaining sites were analyzed further for resource developability and the cost of providing electrical offset by implementing geothermal district heating systems. Of the 145 sites, 46 were found to be very favorable for development, 14 were determined to be favorable, 12 were found to be questionable, and 73 were rated unfavorable for

development in the forseeable future. Site lists are found in the Exhibits of Chapter 2. All data used for the ranking of the sites are in the general Appendices.

9.2 Typical Site Configurations

9.2.1 Introduction

Geothermal resources within the BPA Marketing Area are abundant and have found wide application throughout the region. The first geothermal heating district in the United States was organized and installed in Boise Idaho, in the 1890's. Before then, hot springs were used by Indians, fur trappers, miners, and early settlers for bathing, cooking, and for their reputed healing properties. Today, geothermal resources supply energy for space heating, aquaculture and agricultural production, and industrial processes.

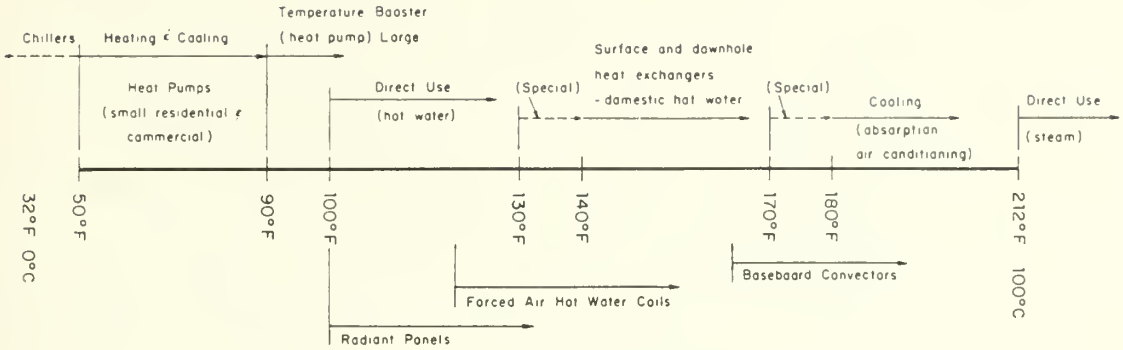
The development of a geothermal resource for a specific use depends upon the resource characteristics and the energy needs of the proposed project. Resource characteristics include the reservoir temperature, the flow rate, and the chemical composition of the geothermal fluid. Temperature requirements for the various uses of geothermal resources are listed in Figure 9.1. Chemical constituents, e.g., total dissolved solids, hydrogen sulfide, arsenic, fluoride, etc., determine the design of the system, materials selection, and the disposal methods of the spent fluids. After heat is extracted from a geothermal resource for one application, the effluent can be used for other direct use projects. For example, a high temperature resource can be used for power production, and its cooler effluent water can be used for industrial processes, space heating, or for agriculture or aquacultural production.

Figure 9.1 - Temperature requirements for various direct geothermal applications.

9.2.2 District Space Heating

Geothermal resources can be used in space heating applications as shown in Figure 9.2. These systems can be used throughout the region for both individual dwellings and for district space heating systems.

In Idaho, there are several examples of district space heating systems. Among these are the Capitol Mall Project in Boise, and the Guyer Hot Springs system in Ketchum.



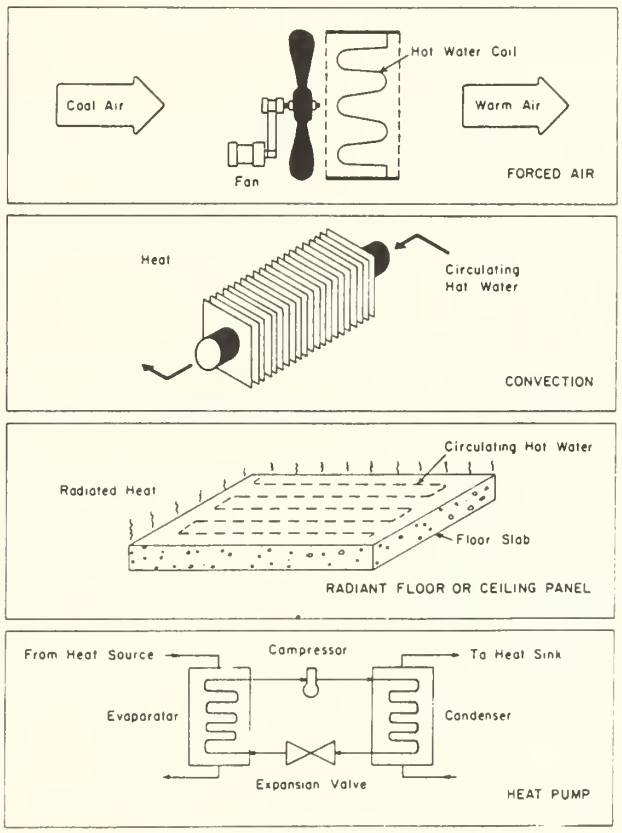


Figure 9.2 - Geothermal space heating systems and temperature indices.

The Boise Capitol Mall project, completed in 1981, provides heat for approximately 67,500 square meters (750,000 sq. ft.) of state offices with 72°C (162°F) water that is circulated to each building through pipes in utility tunnels. Plate-type heat exchangers transfer heat to the air-handling equipment which heats the building through a forced air system. During this heating process, approximately 22°C (40°F) is removed from the geothermal fluid. The spent fluid is then injected back into the ground. Domestic hot water is heated in a similar way. During the summer months, the geothermal resource is used to heat the domestic hot water, but air conditioning needs are handled by a natural gas system. The geothermal resource supplies approximately 90 percent of the total heating needs. Natural gas-fired boilers are used for peaking. A two-speed pump, located at the production well, controls the flow for seasonal use of the resource.

Guyer Hot Springs has been used to heat homes and businesses in the Ketchum, Idaho, area since the 1930's. The hot spring water is first diverted to a concrete tank and piped from there to Bald Mountain Hot Spring resort. Individual homeowners use this service in a number of ways. Some of the homes are heated with a forced air system, whereas others are heated by coils in the floor (see Figure 9.2). The resort uses the water in a swimming pool before disposing of it in the Big Wood River.

A typical direct use district space heating system probably would combine features from both of the above mentioned projects. A production well would be drilled, fluids would be transported by insulated pipes to the buildings where heat would be transferred by means of a heat exchanger to the heat distribution system. The spent fluids would then be injected into a disposal well. Individual buildings could be designed specifically for geothermal heating or could be retrofitted with one of the methods seen in Figure 9.2.

Geothermal district heating technology is well established and in use throughout much of the western U.S., Europe, Japan, and the Soviet Union.

Water-to-air heat pumps, as shown in Figure 9.2, also can be used to provide economical district space heating. The city of Ephrata, Washington, uses the 29°C (84°F) city water supply, together with a heat pump, to heat the courthouse, courthouse annex, and two units of a public housing development. A heat exchanger extracts heat from the water and, using a 300 ton heat pump, transfers the heat to a separate system which circulates 49°C (120°F) water through the heating system. Domestic water is then returned to the main line to meet other municipal needs. This innovative system is the first to use a city's domestic water supply for both heating and home purposes.

9.2.3 The Advantages of Peaking

It is often advantageous to meet base load demands with geothermal energy, and to rely upon boosting with a conventional resource for peak demand. The use of such hybrid systems is especially common in applications that have substantial peak heat demands, such as district heating systems. Peaking is not restricted to systems using very low temperatures but is common even where resources in the 80-100°C range are available.

In order to demonstrate the technical and economic advantages of peaking, two runs were made on a recently completed computer model designed to determine the favorability of district heating. In the first case, a 50°C (122°F) resource located 24 km (15 miles) from Yakima, Washington, was tested to meet the total energy demand of a district heating system. In the second case, the top 50 percent of the peaking curve (Figure 9.3) was provided through use of a fossil fuel peaking boiler. An economic comparison of the two scenarios is shown in Table 9.1.

TABLE 9.1 - District Heating Capital Cost Comparisons

Main System Components	Costs Without Peaking	Costs With Peaking	% Savings
Wells	$ 20.8 million	$ 10.4 million	50%
Main Transmission Line	$ 63.4 million	$ 44.7 million	30%
Distribution Line	$110.9 million	$100.8 million	09%
TOTALS	$195.1 million	$155.9 million	20%

In case two, although 50 percent of the peak demand is met through the use of the fossil fuel fired boiler, only 5 percent of the total energy demand is provided by the peaking boiler.

The main technical advantage of using a peaking boiler is a reduction in the number of wells by approximately 50 percent, and a proportionate reduction in the size of the main transmission line. Distribution lines are also reduced in size but technical and economic advantages are minimal.

In Reykjavik, Iceland where more than 98 percent of the city's 385 MW of total heat demand is provided through a geothermal district heating system, approximately 50 percent of peak demand is met through the use of storage tanks and a 25 MW fossil fuel boiler. The peaking plant, however, provides only 10 percent of the total energy provided on a yearly basis.

A district heating system in Paris, France, utilizes both heat pumps and a peaking boiler (Figure 9.3). As can be seen from the figure, 63 percent of the total energy is provided directly by geothermal energy, 31 percent through the use of the geothermal heat pump system and 6 percent of the total energy is provided by a peaking boiler. As with the Yakima model and the Reykjavik system, approximately 50 percent of the peak demand is provided through the use of a peaking boiler.

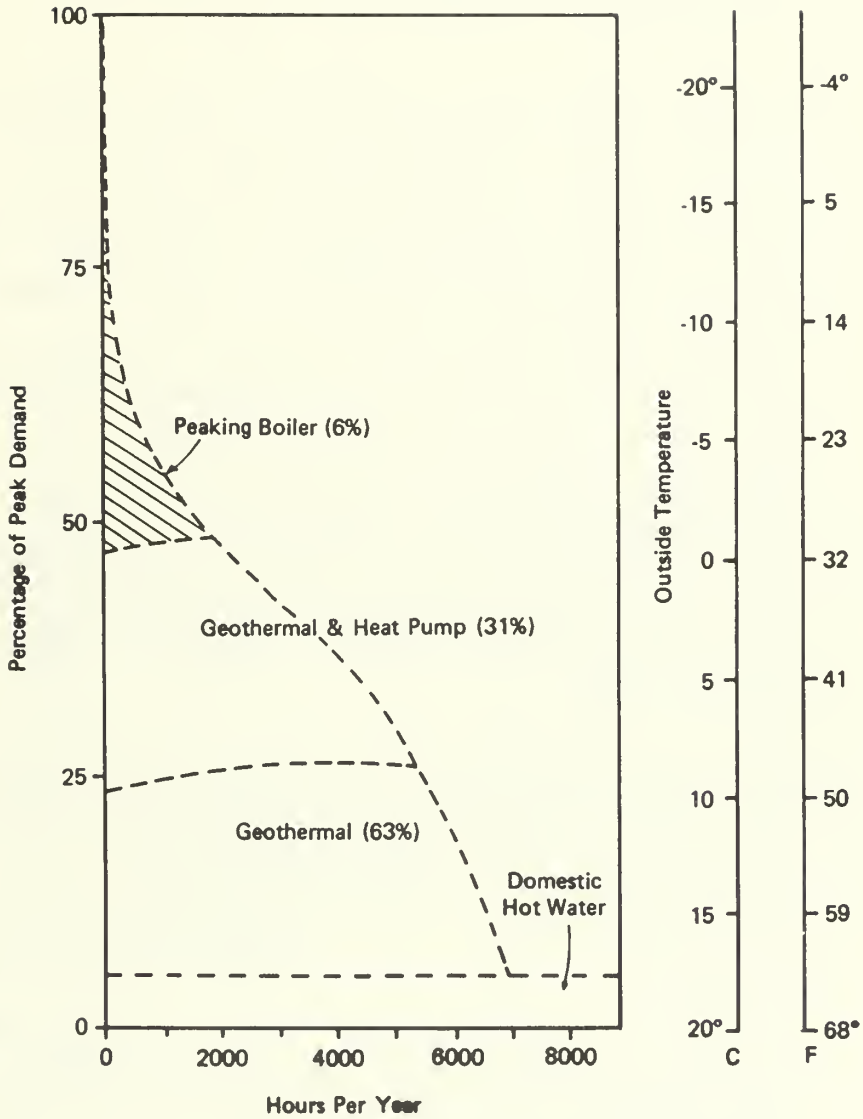


Figure 9.3 - Geothermal city heat load duration curve.

9.2.4 Agricultural and Industrial Uses

Geothermal resources can supply the energy demands of a number of industrial and agricultural applications as shown in Figure 9.1. Examples are onion dehydration at Brady Hot Springs, Nevada, and greenhousing and fish farming near Buhl, Idaho.

At Brady Hot Springs in Nevada, a high temperature (135°C/275°F) resource is used to heat hot water coils which in turn transfer heat by means of high-powered blowers and exhaust fans to the drying ovens. This heated air is circulated through the continuously moving conveyor belt where the moisture is removed from onions. At a certain point during the drying process, the onions are automatically transferred to a second stage of drying where the temperatures are lower. After drying, the onions are sent to the milling area where they are processed for shipment. Such dehydration facilities have historically relied upon natural gas to provide the heat for drying; however, the geothermal resources at Brady are being used successfully to meet the heating requirements, while at the same time providing the operator with a significant economic advantage over his competitors.

Three separate greenhouse operations located on the Snake River near Buhl, Idaho, use geothermal water to provide heat for the greenhouses. Forced air systems using 44°C (111°F) geothermal water, heat more than 10,000 m^2 (26,900 sq. ft.) of greenhouse space. All three operators successfully raise potted flowering plants such as chrysanthemums and poinsettia, in addition to many varieties of bedding plants. None has experienced any problems with the use of the geothermal resource, and all are proponents of the utilization of geothermal resources for economical greenhouse heating.

Trout, catfish, and tilapia are raised in Idaho for commercial purposes. One grower near Buhl produces 300,000 pounds of catfish and

150,000 pounds of tilapia annually in 37°C (98°F) geothermal water. Presently, research is being conducted to determine the feasibility of growing other species such as freshwater prawns in geothermal water.

The technology is presently available for the development of direct use geothermal resources within the BPA marketing area; however, each resource is site specific and the systems need to be designed accordingly. Problems with utilizing the resource, such as corrosion and scaling, can be overcome by proper design and materials selection. The economics and reliability of this indigenous renewable resource have been demonstrated throughout the world and its development should be encouraged.

9.3 Detailed Economic Analyses

9.3.1 Introduction

To evaluate the economics of an individual site, as well as be able to compare and rank all direct use sites within the BPA market area, a comprehensive computer program, HEATPLAN, was selected by the Assessment Group. HEATPLAN (see Appendix 7) (Allen, 1984) was developed by Eliot Allen and Associates in 1983 and 1984 for the Washington State Energy Office to determine the feasibility of district space heating projects on a site specific basis. HEATPLAN was used earlier to analyze several sites in Washington and has been tested on sites in both Oregon and Washington. In all cases, it has proven to be an effective analysis tool.

9.3.2 Discussion of HEATPLAN Methodology

HEATPLAN evaluates a community by the heat demands of its land-uses and the heat supplies that geothermal water can offer. The program estimates a minimum heat price and minimum heat sales per unit of land area necessary for successfully operating a publicly-owned, community-wide system with a 25 year economic life. Twenty-five years were chosen for the economic life of the system based upon the 25 year life of most municipal bonds, and does not reflect the expected life of the resource and/or distribution system.

User-supplied information, computer generated values, and override capabilities give HEATPLAN the versatility to be used over time with increasingly refined input data. In other words, initial runs using rough estimates of values can be replaced later with more exact engineering and economic data. This program versatility also applies to sensitivity analyses. By changing key values, the user is able to simulate the effects of different heating loads, system designs, or financing scenarios.

It should be noted that computer models must inherently contain certain assumptions about project circumstances in order to be used in as many locations and cases as possible. HEATPLAN's assumptions have been developed to reflect as closely as possible state-of-the-art district heating practices. Where subjective judgments or assumptions have been unavoidable, they are purposely conservative. HEATPLAN has been designed to permit overriding of its major assumptions with insertion of actual local or engineering values to increase the accuracy of program output. However, no claim or warranty is made regarding the validity of HEATPLAN results when used for engineering purposes. Rather, **results should be used for comparative analysis of alternatives where percentage increases or decreases are compared to one another, rather than for the determination of actual numeric results.**

HEATPLAN is intended to be a data management tool that can be used for community planning. **District heating prospects can be identified by HEATPLAN, but detailed engineering and economic analyses will always be required before district heating projects are actually implemented.**

9.3.2.1 Program Organization

HEATPLAN is organized into a sequence of program "modules" which quantify heating loads, simulate a district heating system to serve the load, incorporate a geothermal heat source, and calculate life-cycle economics for the system. The modules and their functions are summarized as follows:

Module 1 - Heat Load Information

This module incorporates climatic considerations for building type, size, and age to estimate heat loads for a user-specified acreage. When known, actual heat loads can be entered. Actual heat loads are required input for the incorporation of industrial process loads. With the user-entered initial and ultimate market penetration rates, this module incorporates heat load data to determine peak load and annual loads for those penetration rates.

Module 2 - Distribution System Information

This module contains data related to pipeline lengths, sizes, and the associated costs of construction. It also incorporates the initial and ultimate market penetration rates with the user-designated project life. Pumping requirements, heat pump or heat exchanger sizes, and controlled building construction are all addressed to estimate distribution costs.

Module 3 - Heat Source Information

This module calculates the number of wells needed to serve the estimated heat load (identified in Module 1). Geothermal resource characteristics are entered by the user. Transmission pipeline length from the well(s) to the distribution system is also estimated by the user, along with the option of a peaking boiler. This module calculates the costs of developing the geothermal resource.

Module 4 - Life-Cycle Economics

This module incorporates information from the three previous modules along with user-entered interest and inflation rates to formulate a district heat sales price. The price for public ownership is calculated to provide sufficient funding for successful operation of the system over a 25 year period.

9.3.3 Characteristics of Direct Use Sites

The analysis of the 145 chosen direct use sites focused on the central business districts (CBD) or commercial sectors, with some consideration for adjacent industries and large institutional heat loads. The residential sector was not included within the heat load estimates of the sites because of the high density required for economical district heating development. Even though residential areas adjacent to a CBD could be developed economically as part of the CBD district heating system, a conservative approach was taken by excluding the residential sectors.

A methodology from Allen (1980) is used to determine the commercial sector heat loads. For institutional and industrial heat loads, actual consumption or an estimate based on type and size is used. Only industries with low-temperature process heat loads are included.

The Allen (1980) methodology incorporates population, heating degree days, outside winter design temperature, and a commercial correction factor based on internal heat gains to calculate the commercial sector heat loads. The heat load figures estimated for the direct use sites are used in the HEATPLAN analysis.

In the following tables, the capital costs generated by HEATPLAN and estimates of resource potential (see Chapter 3) are presented. Several important points should be remembered when studying the results.

1. The total exploration program (see Chapter 7) is used in all cases. Realistically, only parts of the three exploration phases would be completed. However, for consistency, and for prudent development of the resource, all phases are considered to be necessary and desirable.

2. Both production and injection wells are considered to be requirements for each system, although in some cases, existing wells could be used. Injection is a preferred method of disposal to avoid

run-off of spent fluids in surface waters, and to maintain aquifer pressures. Injection can lessen thermal and chemical pollution as well as reduce the risk of land subsidence.

3. A 25 year economic life is selected to reflect the life of a municipal bond, not the life of the resource or the system. The sales price is calculated over this life. The program does not calculate a simple payback of the project. Rather, a price to the consumer is calculated which is sufficient for successful operation of the system over the 25 year period.

4. For those sites, where the resource temperature is less than 50°C (120°F) the resource is considered too cold for direct use; therefore, HEATPLAN assumes that a heat pump will be used for boosting the temperature. When using heat pumps, resources with temperatures down to 13°C (55°F) must be considered viable. For this study, however, the cut-off temperature is 10°C above the mean annual ambient air temperature.

5. If an industrial process heating load is near a central core area, it is included in the heat load for purposes of the HEATPLAN analysis. It has been found that only sites in Washington meet this requirement and they have been noted in the following tables.

9.3.4 Discussion of Results

Based upon the district heating sales price, 60 sites (41 percent of the 145 sites selected) are considered economically favorable for development and deserve further detailed analyses (see Table 9.2). A breakdown of favorability, percentages, and energy offsets are found in Table 9.3. However, the remaining sites should not be dismissed but should be given further consideration as more data become available. If commercial or industrial growth occurs or energy economics change, these sites could become viable.

As mentioned earlier, exploration costs included in this analysis are high. This is especially true in Montana where little is known about the resource and considerable exploration is needed before development could occur. Exploration costs can dramatically increase the capital costs of the overall system, especially in smaller cities. A high capital cost combined with a small heat load results in a very high heat sales price for district heating. In most cases, a town with a population of less than 1,000 would be unable to pay for a geothermal district heating system unless a large end-user, such as an industry, were available to anchor the system.

The prices calculated by HEATPLAN should be used for comparative purposes only. Economic data combined with data from Chapter 6 more accurately portray the actual developability of the direct use sites.

TABLE 9.2

	Total Sites	$0 - 10 Very Favorable	$10.01 - 20.00 Favorable	$20.01 - 30.00 Questionable	$30.01 + Unfavorable
Idaho	44	14	8	9	13
Montana	22	4	0	0	18
Oregon	40	8	3	2	27
Washington	39	20	3	1	15
By %					
Idaho		32%	18%	20%	30%
Montana		18%	0%	0%	82%
Oregon		20%	7%	5%	68%
Washington		51%	8%	3%	38%

TABLE 9.3 - Energy Offset and Energy Potential of Direct Use Sites

ENERGY OFFSET OF DIRECT USE SITES

	Very Favorable	Favorable	Total
Idaho	25.7	3.20	28.90
Montana	5.43	0	5.43
Oregon	7.66	1.18	8.84
Washington	87.30	3.55	90.85
Total	126.09 MW	7.93 MW	134.02 MW

ENERGY POTENTIAL OF DIRECT USE SITES

	Very Favorable	Favorable	Total
Idaho	256	125	381
Montana	68	0	68
Oregon	111	60	171
Washington	323	28	351
Total	758	213	971

9.4 Conclusions

Direct use sites that are considered favorable for development by the HEATPLAN analysis should be studied more carefully. Detailed resource assessment, engineering, and heat load designs are warranted. The energy offset potential of some 60 'very favorable' and 'favorable' sites is 134.02 MW. The total energy potential of these sites is 971 MW. This potential should not be overlooked in BPA's regional energy planning programs.

CHAPTER 10

Ranking Results

10.0 RANKING RESULTS

10.1 Introduction

The final geothermal ranking procedure evaluates resources both in terms of their developability and their economic potential. Generally, resources are examined according to two different procedures. The more conventional analysis (see Chapter 8) deals with resource specific engineering and economic factors involved in geothermal site evaluation. The other takes into account additional engineering, environmental and institutional factors. Together the two procedures comprise a comprehensive geothermal site evaluation methodology.

The developability ranking is given by a normalized minimum score between 0 and 1 indicating the relative favorability of that resource site. A high score indicates a very developable site, while a low score indicates a less promising one. These scores are classified by both high and low temperature resources sites and broken out by states. Sites are numbered by their scores to establish a ranking hierarchy. These scores should not be strictly interpreted because uncertainty may exist in the assignment of the numbers. More importantly, the developability ranking procedure is a general and subjective guide. Table 10.1 shows the ordinal ranking of all the Pacific Northwest geothermal high temperature sites. Table 10.2 presents a similar list for direct utilization resource sites.

10.2 Assignment of Sites to Ranking Groups

Following site ranking, the scores are subjected to statistical analysis. Sites are classified into three general groups with a more detailed interpretations. All sites are assigned a place in a normal curve distribution as shown in Figure 10.1. Based on the standard deviation of the distribution, all the sites are categorized into one of three groups. These are: sites with **good** development potential, those with **average** potential and sites with **poor** potential. Most of the sites (about 68 percent) fall into the average class.

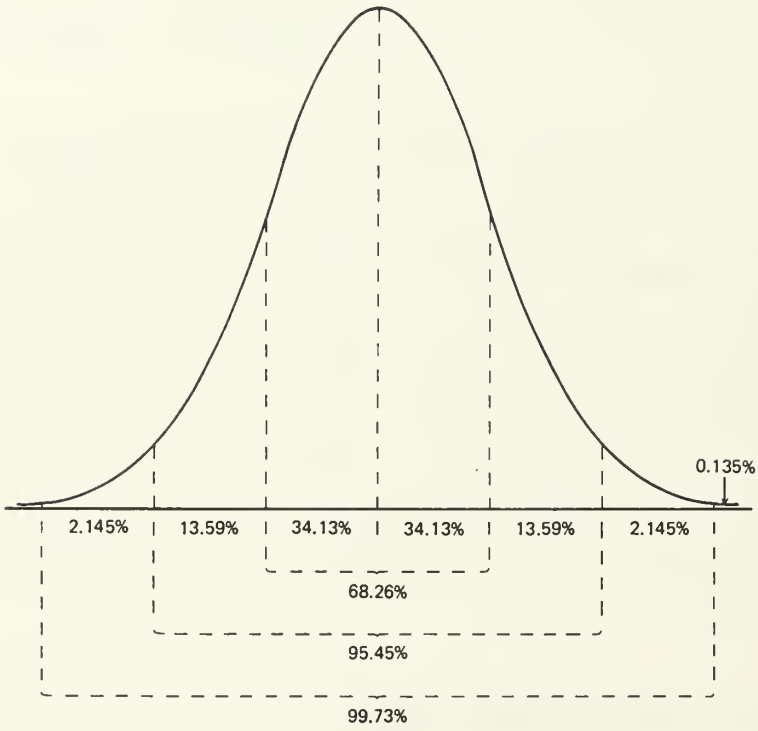


Figure 10.1 - The Normal Distribution

TABLE 10.1 - High Temperature Site Ranking: Pacific Northwest

Rank	Site	Normalized Minimum Score
1	Olene Gap OR	.703
2	Raft River ID	.676
3	Ennis MT	.676
4	Magic Reservoir ID	.670
5	Barry Ranch OR	.660
6	Klamath Hills OR	.645
7	Mt. Baker WA	.643
8	Glass Buttes OR	.639
9	Alvord HS OR	.639
10	Roystone HS ID	.638
11	Klamath Falls Area OR	.635
12	White Arrow HS ID	.633
13	Cove Creek ID	.632
14	Newberry Volcano OR	.632
15	Big Creek HS ID	.632
16	Vale HS OR	.627
17	Lakeview OR	.615
18	Sharkey HS ID	.614
19	Guyer HS ID	.612
20	Squaw Creek HS ID	.608
21	Blackfoot Lava Field ID	.606
22	Rexburg Caldera ID	.606
23	Silverstar MT	.602
24	Battle Creek HS ID	.601
25	Marysville Well MT	.601
26	Hallinan Springs OR	.598
27	Carbonton HS ID	.597
28	Neal HS OR	.597
29	Gregson HS MT	.593
30	Maple Grove HS ID	.591
31	Trout Creek OR	.589
32	White Licks HS ID	.585
33	Mt. Adams WA	.583
34	Borax Lake OR	.581
35	Barrons HS ID	.580
37	Crump Geyser OR	.577
38	Ben Meek Well ID	.575
39	Generic High Cascade OR	.574
40	Mickey HS OR	.573
41	Puny Creek Basalt WA	.572
42	Fisher HS OR	.565
43	Indian Creek HS ID	.562
44	Crater Lake Area OR	.560
45	Murphy Creek HS ID	.558
46	Cappy-Burn Butte OR	.558
47	Melvin/Three Creek Buttes OR	.552
48	Wart Peak Caldera OR	.546
49	Jackson HS MT	.541
50	Devil's Garden OR	.540
51	Sunbeam HS ID	.537
52	China Hat/East Butte OR	.534
53	Bearwallow Butte OR	.529

Rank	Site	Normalized Minimum Score
54	Boiling Springs ID	.528
55	Latty HS ID	.526
56	Mitchell Butte OR	.520
57	Diamond Craters OR	.518
58	Boulder HS MT	.517
59	Four Craters OR	.517
60	Broadwater HS MT	.516
61	McDermott Area OR	.515
62	Bropp HS OR	.515
63	Little Valley Area OR	.513
64	Mt. Hood OR	.512
65	Crane HS OR	.510
66	Weberg HS OR	.506
67	Squaw Ridge OR	.506
68	Mt. McLoughlin OR	.503
69	Blue Mountain HS OR	.501
70	Beulah HS OR	.501
71	Riggins HS ID	.500
72	Kriegbaum HS ID	.498
73	Umpqua OR	.497
74	Jackles Butte OR	.495
75	Quartz Mountain OR	.494
76	Frederick Butte OR	.490
77	Deer HS ID	.488
78	O.J. Thomas Well OR	.488
79	Austin HS OR	.480
80	Luce HS OR	.469
81	Cougar Peak OR	.462
82	Owl Creek HS ID	.459
83	Vulcan HS ID	.455
84	Bigelow OR	.454
85	Foley HS OR	.449
86	Worswick HS ID	.446
87	Wall Creek HS OR	.443
88	Breitenbush HS OR	.437
89	Medical HS OR	.425
90	Bonneville HS ID	.424
91	Island Park Caldera ID	.419
92	McCredie HS OR	.411
93	Kahneeta HS OR	.405
94	Belknap HS OR	.403
95	Rustler Peak OR	.396
96	Jordan Craters OR	.369

TABLE 10.2 - Direct Utilization Sites Ranking: Pacific Northwest

Rank	Site	Normalized Minimum Score
1	Klamath Falls OR	.784
2	Boise ID	.757
3	Yakima WA	.703
4	Paisley OR	.695
5	Union OR	.691
6	Lakeview OR	.657
7	Burns/Hines OR	.652
8	Pocatello ID	.638
9	La Grande OR	.630
10	Garden City ID	.627
11	Pullman WA	.625
12	Bozeman MT	.623
13	Imbler OR	.608
14	Ketchum ID	.607
15	St. Martins HS WA	.606
16	Vale	.605
17	Haines OR	.601
18	Richland WA	.599
19	Adrian OR	.597
20	Pasco WA	.595
21	Pendleton OR	.593
22	Spray OR	.592
23	Fairfield ID	.592
24	Butte City ID	.590
25	Cascade ID	.587
26	Wahkiacus WA	.586
27	Chubbuck ID	.585
28	Grand View ID	.583
29	Stanfield OR	.579
30	Pilot Rock OR	.579
31	Boardman OR	.575
32	Kennewick WA	.575
33	Twin Falls ID	.575
34	Weston OR	.574
35	Ellensburg WA	.574
36	Rexburg ID	.574
37	Athena OR	.573
38	American Falls ID	.573
39	Nampa ID	.567
40	Umatilla OR	.566
41	Hermiston OR	.566
42	Walla Walla WA	.565
43	Echo OR	.564
44	Kahneeta OR	.564
45	Warm Springs Hospital MT	.562
46	White Sulfur Springs MT	.560
47	Challis ID	.559
48	Alhambra MT	.558
49	Ontario OR	.556
50	Heppner OR	.553
51	Ashland OR	.553
52	Baker OR	.551

Rank	Site	Normalized Minimum Score
53	Othello WA	.549
54	Caldwell ID	.549
55	Irrigon OR	.548
56	Mountain Home ID	.548
57	Council ID	.544
58	Cove OR	.544
59	North Bonneville WA	.543
60	Parkdale OR	.543
61	Arlington OR	.543
62	Huntington OR	.542
63	Rajneeshpuram OR	.541
64	College Place wA	.541
65	Ashton ID	.541
66	Mountain Home AFB ID	.541
67	Midvale ID	.540
68	Davenport WA	.539
69	Weiser ID	.539
70	Mabton WA	.538
71	Government Camp OR	.538
72	Pipestone MT	.538
73	Idaho City ID	.538
74	Milton Freewater OR	.537
75	The Dalles OR	.537
76	Cheney WA	.536
77	Buhl ID	.535
78	Harrah WA	.533
79	Grandview WA	.533
80	Lexington OR	.533
81	West Richland WA	.532
82	Campaqua MT	.532
83	Payette ID	.532
84	Soap Lake WA	.531
85	Elkhorn MT	.531
86	Homedale ID	.531
87	Pomeroy WA	.531
88	Camas MT	.529
89	Lind WA	.526
90	Medicine MT	.526
91	Glenns Ferry ID	.525
92	Hansen ID	.524
93	Filer ID	.523
94	Zillah WA	.522
95	Sleeping Child MT	.522
96	Jordan Valley OR	.522
97	Lava Hot Springs ID	.522
98	Stevenson WA	.521
99	Emmett ID	.520
100	Ritzville WA	.519
101	Parma ID	.519
102	Kimberly ID	.519
103	Colfax WA	.518
104	Washucha WA	.516
105	Anaconda MT	.512

Rank	Site	Normalized Minimum Score
106	Paul ID	.509
107	Moses Lake WA	.508
108	Ephrata WA	.508
109	Wenatchee WA	.502
110	Toppenish WA	.502
111	Sunnyside WA	.502
112	Granger WA	.501
113	Idaho Falls ID	.501
114	Paul ID	.509
115	Oakridge OR	.499
116	Deerlodge MT	.499
117	Bedford MT	.495
118	Lolo HS MT	.494
119	Wendt Well MT	.494
120	Clarkston WA	.492
121	Odessa WA	.492
122	Chico HS MT	.492
123	Avon MT	.492
124	Malad City ID	.491
125	Kuna ID	.490
126	Hailey ID	.486
127	Ammon ID	.484
128	Eagle ID	.482
129	Carters Bridge MT	.480
130	Stanley ID	.479
131	Meridian ID	.479
132	Soda Springs ID	.472
133	Bridge Canyon	.468
134	Troutdale OR	.468
135	Benton City WA	.467
136	Connell-Cunningham WA	.466
137	Greyson Spring MT	.462
138	Warden WA	.461
139	Ritter HS OR	.459
140	Prosser WA	.455
141	Corwin HS MT	.453
142	East Wenatchee WA	.451
143	Toston MT	.449
144	Gallogly MT	.448
145	Garrison MT	.445
146	North Powder OR	.444
147	Bear Creek Springs MT	.441
148	Baker's Hole MT	.434
149	Renova MT	.433
150	Quinn's MT	.410

Statistical analysis of the scores of both the direct utilization and high temperature groups indicates that the distribution of the scores is quite normal. The mean, median and mode of the distributions are very close. This suggests that conventional statistical measures should work well for ranking purposes.

TABLE 10.3 - Statistics for High Temperature Ranking Scores

Maximum Score	.7840
Minimum Score	.4100
Mean	.5392
Median	.5370
Mode	.5380
Standard Deviation	.0594
N	150

TABLE 10.4 - Statistics for Direct Utilization Ranking Scores

Maximum Score	.7030
Minimum Score	.3690
Mean	.5426
Median	.5460
Mode	.6320
Standard Deviation	.0735
N	96

Based on the mean value and the standard deviation, sites are classified into these groups. Sites within one standard deviation of the mean are considered average sites. Those with a better score than one standard deviation from the mean are considered sites with **good** development potential; those with scores less than one standard deviation from the mean are considered to have **poor** development potential. Table 10.5 shows the ranking group assignment for high temperature resources; Table 10.6 does the same for the direct utilization resources.

TABLE 10.5 - Ranking Groups for High Temperature Sites

GROUP	SCORE RANGE	NO.	SITES
Good	.703 - .617	16	Olene Gap OR - Vale OR
Average	.616 - .469	62	Lakeview OR - Thomas W. OR
Poor	.468 - .369	18	Austin OR - Jordan Craters OR

TABLE 10.6 - Ranking Groups for Direct Utilization Sites

GROUP	SCORE RANGE	NO.	SITES
Good	.600 - .784	17	Klamath OR - Haines OR
Average	.480 - .599	113	Richland WA - Carter's Bridge MT
Poor	.479 - .410	20	Stanley ID - Quinn's MT

10.3 Ranking Variance by Criteria Group

The team observed that ranking varied considerably by criteria groups; that is, resource, engineering, or environmental/institutional areas. Some resources with very high resource scores had poor scores in other areas and faired poorly in the general ranking procedure. As an illustration of this phenomenon, we chose the normalized scores for the high temperature group with 'above average' total normalized scores. These include the top 16 ranked resources in the high temperature group.

In most of the past geothermal assessment work, analysis has focused strongly on the geothermal resource characteristics of the sites. The reasons for this are twofold. First, the resource characteristics are probably most important to development success. In our study, resource characteristics are the most important criteria in the assessment with 60 points out of 130 (46 percent). Second, the resource characteristics are the most quantitatively accessible of the examined characteristics. We would expect rank by resource to mirror the expectations of previous studies. The results are presented below:

TABLE 10.7 - High Temperature Ranking by Resource Criteria

Rank	Resource	Normalized Score
1	Newberry Volcano	.934
2	Mt. Baker	.759
3	Big Creek	.764
4	Raft River	.736
5	Vale HS	.727
6	Klamath Falls	.719
7	Glass Buttes	.713
8	Klamath Hills	.704
9	Olene Gap	.685
10	Cone Creek	.677
11	Alvord HS	.655
12	Magic Reservoir	.634
13	Barry Ranch	.586
14	Ennis HS	.547
15	White Arrow	.531
16	Roystone HS	.530

Engineering characteristics have the lowest weight (30 points out of 130 or 23 percent) in the procedure. They reflect accessibility problems of the site, proximity to suitable power lines and nearby heating loads for possible cascading of the resource.

TABLE 10.8 - High Temperature Ranking by Engineering Criteria

Rank	Resource	Normalized Score
1	Klamath Falls	.915
2	Roystone HS	.899
3	Ennis HS	.892
4	Barry Ranch	.891
5	White Arrow	.833
6	Magic Reservoir	.831
7	Olene Gap	.812
8	Cone Creek	.771
9	Raft River	.770
10	Klamath Hills	.767
11	Vale HS	.680
12	Mt. Baker	.639
13	Alvord HS	.599
14	Newberry Volcano	.579
15	Glass Buttes	.521
16	Big Creek	.462

Environmental and institutional factors involved in geothermal power development are apt to be both controversial and pivotal in the overall assessment. Quantification of these factors is seldom possible because of their subjective nature. These criteria are allotted 40 points out of 130 in the ranking procedure (31 percent).

TABLE 10.9 - High Temperature Ranking by Environmental/Institutional Criteria

Rank	Resource	Normalized Score
1	Alvord HS	.836
2	White Arrow	.817
3	Barry Ranch	.792
4	Ennis	.786
5	Magic Reservoir	.786
6	Roystone HS	.786
7	Big Creek	.776
8	Olene Gap	.772
9	Glass Buttes	.771
10	Klamath Hills	.629
11	Mt. Baker	.627
12	Cone Creek	.625
13	Vale HS	.572
14	Raft	.564
15	Klamath Falls	.429
16	Newberry Volcano	.412

There are very large differences between the site ranks in each criteria area. Many sites with good resource characteristics have poor scores in the engineering and environmental categories. A linear regression of the normalized resource and environmental scores indicates a correlation between the two characteristics (correlation coefficient = .72). The correlation study shows that the environmental problems are negatively related to the higher scored resource sites. Generally, environmental problems are greater at the more desirable resources. This is illustrated by the fact that the highest scored resource, Newberry Volcano also has the lowest environmental/institutional score.

Engineering criteria seem to be important in deciding the relative attractiveness of resources in the procedure. In particular, the distance to heating load and annual heat load density characteristics appear to be "tie breakers" in the procedure and give significant advantages to sites where cascading may be possible.

10.4 Economic Ranking

The second part of the ranking procedure adds the economic evaluation of the sites to the development potential assessment shown above. This allows a three by three matrix to approximate geothermal development feasibility in the Pacific Northwest area (Figure 10.2 and 10.3). The most attractive resources will be those with both high development potential and low cost of produced or conserved electrical energy. This two-way method is advantageous since it can account for conventionally estimated engineering and economic factors as well as less tangible institutional and market influences.

For high temperature resources, the economic parameter used for relative ranking was the estimated levelized cost of produced electricity from each site. This procedure is described in detail in Chapter 8. Table 10.10 lists the rankings of the 92 high temperature sites in the Pacific Northwest in terms of the estimated levelized costs of electricity. The costs varied from 50.22 mills for the most economically attractive site (Newberry Caldera in Oregon) to 272.93 mills/kWh for the least economically attractive. Tables 10.11 lists the levelized cost of electricity produced from single/double flash technology, all of which are in Oregon. Tables 10.12-10.15 list the levelized costs for the wellhead binary sites by state. Generally, we find that the single/double flash technology yields the most cost effective power production. Also, there is a large qualitative difference between the wellhead sites and these technologies. All the single/double flash sites are modeled as 50 MW resources, while the binary wellhead sites are typically less than 2 MW.

Delivered cost per million Btu was used as the proxy for economic rank of direct use geothermal sites. The cost per million Btu estimated by the HEATPLAN program ranged between $1.10 and $2,732.80. The economic ranking for all 144 direct utilization Pacific Northwest sites is shown in Table 10.17. The results generally show that direct utilization economics are dominated first by load considerations and secondly by the resource quality.

In summary, if we define 80 mills/kWh as a likely boundary for desirable geothermal electricity, this assessment has identified 29 sites with a minimum potential of 964 MW that warrant further study in regional power planning.

8	8	1
8	24	12
0	13	18

Economics ↑

← Developability

Most Developable/Most Economic

1. Newberry Volcano OR
2. Crane Creek ID
3. Klamath Falls OR
4. Glass Buttes OR
5. Big Creek ID
6. Raft River ID
7. Olene Gap OR
8. Klamath Hills OR

Figure 10.2 - High Temperature Economic/Developability Matrix

5	16	2
10	29	9
8	51	13

Economics ↑

← Developability

Most Developable/Most Economic

1. Boise ID
2. Yakima WA
3. Pocatello ID
4. Pullman WA
5. Klamath Falls OR

Figure 10.3 - Direct Utilization Economic/Developability Matrix

These include all 19 single/double flash sites in Table 10.11 and ten other wellhead sites in the four state area. Of these 29 sites, 22 are located in Oregon, five are in Idaho and two are in Montana.

10.5 Final Ranking

The final ranking was rendered in an uncomplicated fashion. The weight of the ordinal ranks of both the economic and developability rankings were considered equal, so that the final rank was the average of the two.

The results are shown in Table 10.17 for high temperature resources and 10.18 for direct utilization ones. The tables list both the rankings for developability as well as economics along with the average used for the final ranking. Generally, we see that the high temperature ranking procedures agree better than the direct utilization ones. Of course, we would not expect them to fully agree in any case, since the developability ranking measures several qualitative concerns that are not addressed in the economic assessment.

It is important not to misinterpret (statistically) the results of this ranking procedure. Generally, the positional ranking of a site is not very robust (sensitive) to the uncertainties and quality of data used for the assessments. A better indication of the attractiveness of a site is shown by an examination of the group to which the site belongs.

When we analyzed the ranking of the sites, it was decided that application of a normal distribution to the results would be a useful way to understand the significance of the rankings. Sixty eight percent of all sites would be within one standard deviation of the mean in such a distribution. Since ranking scores are not normal, the median was used as the appropriate measure of central tendency. Thus, about 34 percent of sites on either side of the median point are considered as "average" sites. Those with lower scores are considered good sites, and those with greater scores as "poor" ones.

For the direct utilization sites, this means that sites 24 - 119 will be "average" sites, sites 1 - 23 "good" and 120 - 143 "poor" for the ranking purposes. For the economic results of the direct utilization ranking, sites 72 - 143 will arbitrarily be considered as "poor sites" since they have costs in excess of $30 per million Btus.

For high temperature sites, sites 18 - 62 are in the "average" category, 1 - 17 are in the "good" group and 63 - 92 in the "poor" group. This is the same for both the developability and economic rankings.

Thus, a total of forty sites are in the "good" category although this varies by the type of ranking applied. If we apply a three by three matrix to the problem, indexing by both ranking methods, we can see which sites did well on both methods. Figure 10.2 presents this assessment for high temperature sites and 10.3 for direct utilization ones. Eight high temperature sites are identified as having both a superior developability ranking and a good economic ranking. These are listed in alphabetical order in Table 10.19.

TABLE 10.10 - Levelized Cost of Geothermal Electricity
Pacific Northwest Sites

	Site	Mills/kWh
1.	Newberry Caldera, OR	50.22
2.	Wart Peak, OR	53.40
3.	Crane Creek, ID	53.88
4.	Mickey, OR	55.25
5.	Klamath Falls, OR	55.25
6.	Bearwallow Butte, OR	56.84
7.	Melvin/Three Creeks, OR	56.96
8.	Cappy/Burn Butte, OR	57.37
9.	Glass Buttes, OR	58.03
10.	Vulcan, ID	59.48
11.	Big Creek, ID	61.49
12.	Raft River, ID	62.71
13.	Olene Gap, OR	64.78
14.	Neal, OR	64.79
15.	Crump Geyser, OR	64.95
16.	Klamath Hills, OR	65.04
17.	Borax Lake, OR	66.11
18.	Alvord, OR	67.07
19.	Trout Creek, OR	67.37
20.	Crater Lake, OR	69.98
21.	Generic Cascade, OR	70.85
22.	Mt. McLoughlin, OR	71.72
23.	White Licks, ID	73.02
24.	Lakeview, OR	75.19
25.	Boulder, MT	76.37
26.	Ennis, MT	78.23
27.	Summer Lake, OR	78.39
28.	Hallinan Springs, OR	79.17
29.	Vale, OR	79.55
30.	Barry Ranch, OR	81.20
31.	Fischer, OR	82.44
32.	Deer Creek, OR	86.32
33.	Magic Reservoir, OR	87.12
34.	Silver Star, MT	87.36
35.	Roystone, ID	88.92
36.	Jackson, MT	89.69
37.	Mt. Baker, WA	92.17
38.	Mt. Hood, OR	96.79
39.	Gregson, MT	98.63
40.	Broadway, MT	100.46
41.	Owl Creek, ID	104.44
42.	White Arrow, ID	106.89
43.	Squaw Creek, ID	110.84
44.	Crane, OR	118.62
45.	Norris, MT	120.61
46.	Sharkey, ID	120.77
47.	Battle Creek, ID	123.39
48.	Umpqua, OR	125.38
49.	Little Valley, OR	126.00
50.	O. J. Thomas Well, OR	127.04
51.	Indian Creek, ID	128.09

	Site	Mills/kWh
52.	Luce, OR	128.13
53.	Bonneville, ID	136.26
54.	Belknap, OR	136.71
55.	Marysville Well, MT	140.61
56.	Beulah, OR	144.01
57.	Carbarton, ID	145.22
58.	Breitenbush, OR	149.29
59.	Weberg, OR	150.74
60.	Maple Grove, ID	151.31
61.	Krigbaum, ID	153.66
62.	Barrons, ID	154.24
63.	Murphy, ID	155.48
64.	Blue Mtn., OR	161.84
65.	Riggins, ID	161.95
66.	Foley, OR	169.01
67.	Ben Meek Well, ID	179.38
68.	Boiling Springs, OR	180.75
69.	Bigelow, OR	181.50
70.	Guyer, ID	182.42
71.	Latty, ID	182.48
72.	Rustler Peak, OR	182.86
73.	Squaw Ridge, OR	189.47
74.	Quartz Mtn., OR	189.92
75.	Sunbeam, OR	191.71
76.	Devil's Garden, OR	192.57
77.	Cougar Peak, OR	194.13
78.	Diamond Craters, OR	194.13
79.	Austin, OR	195.17
80.	China Hat, OR	196.61
81.	Four Craters, OR	198.00
82.	Frederick Butte, OR	202.36
83.	McCredie, OR	219.09
84.	Kropp, OR	219.50
85.	Medical Springs, OR	231.64
86.	Jordan Craters, OR	233.10
87.	Kahneeta, OR	235.66
88.	Jackies Butte, OR	239.47
89.	Worwick, ID	255.87
90.	Mitchell Butte, OR	267.55
91.	Wall Creek, OR	271.59
92.	McDermitt, OR	272.93

TABLE 10.11 - Levelized Cost of Geothermal Electricity
Oregon Single/Double Flash Sites

	Site	Mills/kWh
1.	Newberry Caldera	50.22
2.	Wart Peak	53.40
3.	Mickey	55.25
4.	Klamath Falls	55.25
5.	Bearwallow Butte	56.84
6.	Melvin/Three Creeks	56.96
7.	Cappy/Burn Butte	57.37
8.	Glass Buttes	58.03
9.	Olene Gap	64.78
10.	Neal	64.79
11.	Crump Geyser	64.95
12.	Klamath Hills	65.04
13.	Borax Lake	66.11
14.	Alvord	67.07
15.	Trout Creek	67.37
16.	Crater Lake	69.98
17.	Generic Cascade	70.85
18.	Mt. McLoughlin	71.72
19.	Vale	79.55

TABLE 10.12 - Levelized Cost of Geothermal Electricity
Idaho Wellhead Binary Sites

	Site	Mills/kWh
1.	Crane Creek	53.88
2.	Vulcan	59.48
3.	Big Creek	61.49
4.	Raft River	62.71
5.	Deer Creek	86.32
6.	Magic Reservoir	87.12
7.	Roystone	88.92
8.	Owl Creek	104.44
9.	White Arrow	106.89
10.	Squaw Creek	110.84
11.	Sharkey	120.77
12.	Battle Creek	123.39
13.	Indian Creek	128.06
14.	Bonneville	136.26
15.	Carbarton	145.22
16.	Maple Grove	151.31
17.	Krigbaum	153.66
18.	Barrons	154.24
19.	Murphy	155.48
20.	Riggins	161.95
21.	Ben Meek Well	179.38
22.	Boiling Springs	180.75
23.	Guyer	182.42
24.	Latty	182.48
25.	Sunbeam	191.71
26.	Worswick	255.87

TABLE 10.13 - Levelized Cost of Geothermal Electricity
Oregon Wellhead Binary Sites

	Site	Mills/kWh
1.	Lakeview	75.19
2.	Summer Lake	78.39
3.	Hallinan Springs	79.17
4.	Barry Ranch	81.20
5.	Fischer HS	82.44
6.	Mt. Hood	96.79
7.	Crane	118.62
8.	Umpqua	125.38
9.	Little Valley	126.00
10.	O. J. Thomas Well	127.04
11.	Luce	128.13
12.	Belknap	136.71
13.	Beulah	144.01
14.	Breitenbush	149.29
15.	Weberg	150.74
16.	Blue Mtn.	161.84
17.	Foley	169.01
18.	Bigelow	181.50
19.	Rustler Peak	182.86
20.	Squaw Ridge	189.47
21.	Quartz Mtn.	189.92
22.	Devil's Garden	192.57
23.	Cougar Peak	194.13
24.	Diamond Craters	194.13
25.	Austin	195.17
26.	China Hat	196.61
27.	Four Craters	198.00
28.	Frederick Butte	202.36
29.	McCredie	219.09
30.	Kropp	219.50
31.	Medical Springs	231.64
32.	Jordan Craters	233.10
33.	Kahneeta	235.66
34.	Jackies Butte	239.47
35.	Mitchell Butte	267.55
36.	Wall Creek	271.59
37.	McDermitt	272.93

TABLE 10.14 - Levelized Cost of Geothermal Electricity
Montana Wellhead Binary Sites

	Site	Mills/kWh
1.	Boulder	76.37
2.	Ennis	78.23
3.	Silver Star	87.36
4.	Jackson	89.69
5.	Gregson	98.63
6.	Broadwater	100.46
7.	Norris	120.61
8.	Marysville Well	140.61

TABLE 10.15 - Levelized Cost of Geothermal Electricity
Washington Wellhead Binary Sites

	Site	Mills/kWh
1.	Mt. Baker	92.17

TABLE 10.16 - Direct Utilization Economic Ranking: Pacific Northwest

Rank	Site	$/MBTU
1	Pullman, WA	1.10
2	Ellensburg, WA	1.22
3	Boise, ID	1.25
4	Hermiston, OR	1.53
5	Pocatello, ID	1.60
6	Yakima, WA	1.68
7	Twin Falls, ID	1.81
8	Sunnyside, WA	1.91
9	Warden, WA	2.07
10	Walla Wall, WA	2.08
11	Prosser, WA	2.11
12	Nampa, ID	2.50
13	Kennewick WA	2.80
14	Othello, WA	2.91
15	Ashland, OR	3.23
16	Grandview, WA	3.24
17	Toppenish, WA	3.57
18	Cheney, WA	3.67
19	Caldwell, ID	3.77
20	Klamath Falls, OR	4.02
21	Wenatchee, WA	4.34
22	Idaho Falls, ID	4.54
23	Anaconda, MT	4.99
24	LaGrande, OR	5.19
25	Rexburg, ID	5.25
26	The Dalles, OR	5.25
27	Zillah, WA	6.52
28	Chubbuck, ID	6.93
29	Moses Lake, WA	7.29
30	Deer Lodge, MT	7.35
31	Pendleton, OR	7.62
32	Ontario, OR	7.65
33	Payett, ID	7.65
34	Vale, OR	7.83
35	Soda Springs, ID	7.88
36	Connell, WA	8.22
37	Pasco, WA	8.40
38	College Park, WA	8.49
39	Meridian, ID	8.76
40	Colfax, WA	9.02
41	American Falls, ID	9.16
42	Buhl, ID	9.18
43	East Wenatchee, WA	9.56
44	Weiser, ID	9.86
45	Emmett, ID	10.39
46	Paisley, OR	10.72
47	Granger, WA	13.28
48	Oakridge, OR	13.50
49	Preston, ID	14.28
50	Garden City, ID	14.47
51	Bozeman, MT	15.17
52	Ephrata, WA	15.35

Rank	Site	$/MBTU
53	Baker, OR	16.33
54	Ketchum, ID	17.45
55	Hailey, ID	17.55
56	Richland, WA	17.63
57	Council, ID	17.67
58	Mountain Home AFB, ID	18.36
59	Parma, ID	19.54
60	Milton Freewater, OR	20.13
61	Glenns Ferry, ID	21.07
62	Cascade, ID	21.58
63	Ammon, ID	21.59
64	Lakeview, OR	21.79
65	Clarkston, WA	22.76
66	Mountain Home, ID	22.90
67	Filer, ID	24.78
68	Kimberly, ID	24.96
69	Eagle, ID	25.22
70	Kuna, ID	27.82
71	Malad City, ID	28.25
72	Umatilla, OR	32.25
73	Heppner, OR	36.02
74	Ashton, ID	33.13
75	Livingston, MT	33.35
76	White Sulphur Sp., MT	34.40
77	Challis, ID	37.99
78	Paul, ID	40.91
79	Burns, OR	41.11
80	Stevenson, WA	41.16
81	Camas, MT	41.45
82	Union, OR	43.27
83	Troutdale, OR	45.02
84	Homedale, ID	45.67
85	Kahneeta, OR	46.50
86	Irrigon, OR	49.18
87	Hansen, ID	54.21
88	Fairfield, ID	55.84
89	Whitehall, MT	58.76
90	Soap Lake, WA	59.79
91	Rajneeshpuram, OR	62.22
92	Stanfield, OR	64.85
93	Pomeroy, WA	68.17
94	Lava Hot Springs, ID	72.19
95	Boardman, OR	81.58
96	Huntington, OR	94.54
97	Government Camp, OR	94.82
98	Parkdale, OR	94.92
99	West Richland, WA	94.95
100	Paradise, MT	95.33
101	Midvale, ID	95.33
102	Pilot Rock, OR	96.07
103	Echo, OR	100.59
104	Idaho City, ID	106.47
105	Arlington, OR	109.04
106	Athena, OR	112.25

Rank	Site	$/MBTU
107	Ritzville, WA	116.06
108	Avon, MT	129.92
109	Gardiner, MT	134.43
110	Odessa, WA	137.50
111	Harrah, WA	138.68
112	Weston, OR	145.40
113	Hot Springs, MT	146.40
114	Clancy, MT	157.96
115	Grantsdale, MT	164.67
116	Benton City, WA	166.19
117	Haines, OR	173.19
118	Townsend, MT	173.53
119	North Bonneville, WA	182.63
120	Lolo, MT	185.22
121	Grandview, ID	185.62
122	Melba, ID	196.37
123	Lexington, OR	200.50
124	Davenport, WA	211.34
125	Mabton, WA	214.17
126	Adrian, OR	249.71
127	North Powder, OR	279.28
128	Garrison, MT	315.29
129	Cove, OR	327.12
130	Wahkiacus, WA	329.20
131	Spray, OR	355.36
132	Jordan Valley, OR	375.24
133	Washtucna, WA	377.27
134	St. Martins, WA	387.42
135	Lind, WA	411.14
136	Ritter, OR	418.57
137	Imbler, OR	555.12
138	Butte City, ID	583.57
139	Stanley, ID	765.26
140	Medicine Sp., MT	1,033.29
141	Polaris, MT	2,562.75
142	Sula, MT	2,576.08
143	Toston, MT	2,732.80

TABLE 10.17 - Final High Temperature Ranking: Pacific Northwest

Site	Devpt	Econ	Final
Raft River, ID	2	12	7.0
Olene Gap, OR	1	13	7.0
Newberry Volcano, OR	14	1	7.5
Crane Creek, ID	13	3	8.0
Klamath Falls, OR	11	5	8.0
Glass Buttes, OR	8	9	8.5
Klamath Hills, OR	6	16	11.0
Big Creek, ID	15	11	13.0
Alvord HS, OR	9	18	13.5
Ennis, MT	3	26	14.5
Barry Ranch, OR	5	30	17.5
Magic Reservoir, ID	4	33	18.5
Neal, OR	26	14	20.0
Mickey, OR	37	4	20.5
Lakeview, OR	17	24	20.5
Mt. Baker, WA	7	37	22.0
Vale, OR	16	19	22.5
Roystone, ID	10	35	22.5
Wart Peak, OR	44	2	23.0
Crump Geyser, OR	33	15	24.0
Borax Lake, OR	31	17	24.0
Trout Creek, OR	29	29	24.0
Melvin/Three Creek, OR	43	7	25.0
Cappy/Burn Butte, OR	42	8	25.0
Hallinan Springs, OR	24	28	26.0
White Licks, ID	30	23	26.5
White Arrow, ID	12	42	27.0
Bearwallow Butte, OR	49	6	27.5
Silver Star, MT	21	34	27.5
Generic High Cascade, OR	36	21	28.5
Crater Lake, OR	40	20	30.0
Summer Lake, OR	34	27	30.5
Squaw Creek, ID	20	43	31.5
Sharkey, ID	18	46	32.0
Gregson, MT	27	39	33.0
Fisher, OR	38	31	34.5
Battle Creek, ID	22	47	34.5
Marysville Well, MT	23	55	39.0
Boulder, MT	54	25	39.5
Jackson, MT	45	36	40.5
Carbarton, ID	25	57	41.0
Mt. McLoughlin, OR	64	22	43.0
Maple Grove, ID	28	60	44.0
Guyer, ID	19	70	44.5
Vulcan, ID	80	10	45.0
Indian Creek, ID	39	51	45.0
Barrons, ID	32	62	47.0
Broadwater, MT	56	40	48.0
Mt. Hood, OR	60	38	49.0
Ben Meek Well, ID	35	67	51.0
Murphy Creek, ID	41	63	52.0

Site	Devpt	Econ	Final
Deer Creek, ID	73	32	52.5
Crane, OR	61	44	52.5
Little Valley, OR	59	49	54.0
Umpqua, OR	69	48	58.5
Boiling Springs, ID	50	68	59.0
Owl Creek, ID	79	41	60.0
Norris, MT	76	45	60.5
Weberg, OR	62	59	60.5
Beulah, OR	66	56	61.0
Latty, ID	51	71	61.0
Sunbeam, ID	47	75	61.0
Devil's Garden, OR	46	76	61.0
O.J. Thomas Well, OR	74	50	62.0
China Hat, OR	48	80	64.0
Luce, OR	77	52	64.5
Krigbaum, ID	68	61	64.5
Blue Mtn., OR	65	64	64.5
Diamond Craters, OR	53	78	65.5
Riggins, ID	67	65	66.0
Squaw Ridge, OR	63	73	68.0
Four Craters, OR	55	81	68.0
Bonneville, ID	87	53	70.0
Kropp, OR	58	84	71.0
Mitchell Butte, OR	52	90	71.0
Breitenbush, OR	85	58	71.5
Belknap, OR	90	54	72.0
Quartz Mtn., OR	71	74	72.5
Foley, OR	82	66	74.0
McDermitt, OR	57	92	74.5
Bigelow, OR	81	69	75.0
Austin, OR	75	79	77.0
Frederick Butte, OR	72	82	77.0
Cougar Peak, OR	78	77	77.5
Jackies Butte, OR	70	88	79.0
Rustler Peak	91	72	81.5
McCredie, OR	88	83	85.5
Medical Springs, OR	86	85	85.5
Worswick, ID	83	89	86.0
Wall Creek, OR	84	91	87.5
Kahneeta, OR	89	87	88.0
Jordan Craters	92	86	89.0

TABLE 10.18 - Direct Utilization Ranking: Pacific Northwest

Site	Devpt	Econ	Final
Boise, ID	2	3	2.5
Yakima, WA	3	6	4.5
Pullman, WA	11	1	6.0
Pocatello, ID	8	5	6.5
Klamath Falls, OR	1	20	10.5
La Grande, OR	9	24	16.5
Ellensburg, WA	36	2	19.0
Twin Falls, ID	34	7	20.5
Kennewick, WA	33	13	23.0
Hermiston, OR	42	4	23.0
Paisley, OR	4	46	25.0
Vale, OR	16	34	25.0
Pendleton, OR	21	31	26.0
Nampa, ID	40	12	26.0
Walla Walla, WA	43	10	26.5
Chubbuck, ID	28	28	28.0
Pasco, WA	20	37	28.5
Garden City, ID	10	50	30.0
Rexburg, ID	37	25	31.0
Bozeman, MT	12	51	31.5
Ashland, OR	51	15	33.0
Othello, WA	53	14	33.5
Ketchum, ID	14	54	34.0
Lakeview, OR	6	64	35.0
Preston, ID	24	49	36.5
Caldwell, ID	54	19	36.5
Richland, WA	18	56	37.0
American Falls, ID	39	41	40.0
Ontario, OR	49	32	40.5
Burns Hines, OR	7	79	43.0
Union, OR	5	82	43.5
Cascade, ID	26	62	44.0
Cheney, WA	76	18	47.0
Grandview, WA	79	16	47.5
The Dalles, OR	75	26	50.5
College Park, WA	64	38	51.0
Baker, OR	52	53	52.5
Fairfield, ID	23	88	55.5
Umatilla, OR	41	72	56.5
Weiser, ID	69	44	56.5
Council, ID	57	57	57.0
Payette, ID	83	33	58.0
Buhl, ID	77	42	59.5
Sunnyside, WA	111	8	59.5
Zillah, WA	94	27	60.5
Stanfield, OR	30	92	61.0
White Sulfur Springs, MT	46	76	61.0
Mountain Home, ID	56	66	61.0
Heppner, OR	50	73	61.5
Challis, ID	47	77	62.0
Mountain Home AFB, ID	66	58	62.0

Site	Devpt	Econ	Final
Boardman, OR	32	95	63.5
Toppenish, WA	110	17	63.5
Anaconda, MT	105	23	64.0
Kahneeta, OR	45	85	65.0
Wenatchee, WA	109	21	65.0
Pilot Rock, OR	31	102	66.5
Haines, OR	17	117	67.0
Milton Freewater, OR	74	60	67.0
Idaho Falls, ID	113	22	67.5
Moses Lake, WA	107	29	68.0
Ashton, ID	65	74	69.5
Irrigon, OR	55	86	70.5
Colfax, WA	103	40	71.5
Warden, WA	134	9	71.5
Athena, OR	38	106	72.0
Emmett, ID	99	45	72.0
Adrian, OR	19	126	72.5
Deer Lodge, MT	116	30	73.0
Weston, OR	35	112	73.5
Echo, OR	44	103	73.5
Prosser, WA	136	11	73.5
St. Martins, WA	15	134	74.5
Imbler, OR	13	137	75.0
Grand View, ID	29	121	75.0
Glenns Ferry, ID	91	61	76.0
Spray, OR	22	131	76.5
Rajneeshpuram, OR	63	91	77.0
Wahkiacus, WA	27	130	78.5
Parkdale, OR	60	98	79.0
Huntington, OR	62	96	79.0
Granger, WA	112	47	79.5
Filer, ID	93	67	80.0
Parma, ID	101	59	80.0
Ephrata, WA	108	52	80.0
Whitehall, MT	72	89	80.5
Clancy, MT	48	114	81.0
Butte City, ID	25	138	81.5
Oakridge, OR	115	48	81.5
Soda Springs, ID	130	35	82.5
Arlington, OR	61	105	83.0
Midvale, ID	67	101	84.0
Government Camp, OR	71	97	84.0
Meridian, ID	129	39	84.0
Camas, MT	88	81	84.5
Connell, WA	133	36	84.5
Homedale, ID	86	84	85.0
Kimberly, ID	102	68	85.0
Soap Lake, WA	84	90	87.0
Idaho City, ID	73	104	88.5
North Bonneville, WA	59	119	89.0
Stevenson, WA	98	80	89.0
Hansen, ID	92	87	89.5
West Richland, WA	81	99	90.0
Pomeroy, WA	87	93	90.0

Site	Devpt	Econ	Final
Hailey, ID	125	55	90.0
East Wenatchee, WA	138	43	90.5
Paul, ID	106	78	92.0
Clarkston, WA	119	65	92.0
Cove, OR	58	129	93.5
Harrah, WA	78	111	94.5
Ammon, ID	126	63	94.5
Lava Hot Springs, ID	97	94	95.5
Davenport, WA	68	124	96.0
Lexington, OR	70	123	96.5
Malad City, ID	123	71	97.0
Kuna, ID	124	70	97.0
Mabton, WA	70	125	97.5
Hot Springs, MT	82	113	97.5
Livingston, MT	121	75	98.0
Eagle, ID	127	69	98.0
Ritzville, WA	100	107	103.5
Grantsdale, MT	95	115	105.0
Troutdale, OR	131	83	107.0
Lind, WA	89	135	112.0
Polaris, MT	85	141	113.0
Jordan Valley, OR	96	132	114.0
Medicine Springs, MT	90	140	115.0
Odessa, WA	120	110	115.0
Avon, MT	122	108	115.0
Townsend, MT	117	118	117.5
Melba, ID	114	122	118.0
Washtucna, WA	104	133	118.5
Lolo, MT	118	120	119.0
Paradise, MT	143	100	121.5
Gardiner, MT	137	109	123.0
Benton City, WA	132	116	124.0
Stanley, ID	128	139	133.5
Garrison, MT	141	128	134.5
North Powder, OR	142	127	134.5
Ritter, OR	135	136	135.5
Toston, MT	139	143	141.0
Sula, MT	140	142	141.0

TABLE 10.19 - High Temperature Sites
Highly Developable/Highly Economic

1. Big Creek, ID
2. Crane Creek, ID
3. Glass Buttes, OR
4. Klamath Falls, OR
5. Klamath Hill, OR
6. Olene Gap, OR
7. Newberry Caldera, OR
8. Raft River, ID

Five direct utilization sites are identified by the matrix and are listed alphabetically in Table 10.20. Note that the matrix is strongly skewed towards the poor results because of the economically feasible cutoff point of $30 per million Btus.

TABLE 10.20 - Direct Utilization Sites
Highly Developable/Highly Economic

1. Boise, ID
2. Klamath Falls, OR
3. Pocatello, ID
4. Pullman, WA
5. Yakima, WA

10.6 Study Caveats

A number of limitations which affected this study should be noted:

1. The developability ranking necessarily is somewhat subjective since it uses "expert opinion" for qualitative concerns. To the extent that this opinion may be incorrect or biased, it does not reflect actual conditions.

2. Many complex assumptions are used in the individual site assessments such as depth of resource, flow rates, etc. These assumptions tend to group the assessments more loosely than would occur if more precise data were known. More case specific data is desirable for a more complete treatment

of the assessments of this report. Generally, the methods employed tend to create a bias in favor of sites with more complete information since the certainty of the inputs is more favorable.

3. The GEORANK program probably does not give sufficient weight to heat load and heat load density. This is based on results from the HEATPLAN program in the project. This factor is responsible for most of the disagreement between the direct utilization ranking results and the corresponding economic ranking.

4. The levelized cost procedure uses the most likely values for analysis, whereas the true mean levelized cost of electricity under uncertainty in the production variables is the intergral of the cumulative range of expected values for each function. This can be estimated through the use of Monte Carlo simulation. This can be very important when some of the variables such as project life have a most likely value of 30 years, but the range of uncertainty falls between 15 and 30 years. As shown in Chapter 8, this has a large effect on estimated levelized costs.

5. The HEATPLAN program only addresses district heating project feasibility and does not cover small scale direct utilization geothermal applications that may be economically attractive. This includes applications such as greenhouse and resort heating that may be economically advantageous even though the HEATPLAN results show the heat loads to be too small to result in a viable project.

6. The direct utilization results do not account for the fact that loads may change over the project life that could have serious effects on the economics. Of course, this could go either way. If new development moved in to take advantage of low cost heat, the overall costs would be reduced for supplying a given amount of heat. On the other hand, if population decreased or loads decreased as a result of conservation efforts, the economic benefits are reduced.

7. There are certain sites where additional new data are available that could alter some of the results of the study, however the data is proprietary. Even though some of the project members are aware of this data, "we can't know we know it."

10.7 Summary

Out of 234 Pacific Northwest geothermal resource sites where enough data are available for ranking purposes, some forty are identified in this procedure as possessing a superior development or economic potential. Seventeen of these are high temperature sites and 23 are direct utilization ones. The better sites tend to be concentrated in Oregon both in terms of quality and number.

The combined development and economic rankings can be used to assist in determining sites with superior characteristics of both types. Five direct utilization sites and eight high temperature sites are identified with both high development and economic potential. An additional 27 sites are shown as having superior economic characteristics, but development problems.

The procedure seems validated by the fact that two of the highest ranking direct utilization sites are ones that have already been developed -- Boise, Idaho and Klamath Falls, Oregon. Most of the higher ranking high temperature sites have received serious examination in the past as likely power production candidates such as Newberry Volcano in Oregon.

The ranking results should only be considered significant when taken as groups of **good, average** and **poor** sites. The results can be used as a guide for future definition of sites that should receive further study.

10.8 Further Work

One of the important results of the study has been expanding definitions of work that needs to be completed in order to aid resource development and cost effectiveness determination.

Based on our study, the team believes that more detailed assessment work is the most significant barrier remaining. This includes a greater definition of the some the attractive resources identified here in terms of geology, geophysics and in some cases exploratory drilling and reservoir testing. Given the poor level of

knowledge of geothermal systems, this is required in order to be reasonably certain of being able to develop viable electrical generation systems. For direct utilization systems, this includes a more detailed characterization of the heating load.

More detailed economic estimates need to be produced for the attractive resources. This should be based on known data and input into a Monte Carlo model with the remaining uncertainties modeled as random variables to ascertain the effect on the levelized cost of the produced or offset power.

In general, the results from this study can be used to identify resources that should be studied in a detailed fashion. The results of this work would include a substantial improvement in the knowledge of the cost of geothermal power and a better estimate of the geothermal potential in the Pacific Northwest.

CHAPTER 11

Summary and Recommendations

Summary and Recommendations

Commercial geothermal utilization in the Pacific Northwest region began nearly 100 years ago with the installation of the Warm Springs Heating District in Boise, Idaho. Despite its early start and the efforts of the United States Department of Energy and the United States Geological Survey geothermal development has been very slow and only a fraction of 1 percent of the total regional geothermal potential identified in this study has been developed.

This lack of geothermal development can be directly related to a lack of basic information about the quality and extent of exploitable geothermal resources in the region. In 1983 this lack of information resulted in the Bonneville Power Administration requesting that the Washington State Energy Office (WSEO) coordinate a detailed regional geothermal assessment program which would bring together the expertise existing in state energy and resource agencies throughout the four state region. The objective of the assessment program was to consolidate and evaluate all geologic, environmental, legal and institutional information in existing records and files, and to apply a uniform methodology to the evaluation and ranking of all sites in the region, so that credible forecasts could be made of the geothermal energy available in the region for electrical generation or electrical load offset.

Four tasks were determined to be essential to meet these objectives:

1. Characterization of potential electrical generation resource sites (i.e., those sites with temperatures greater than 90°C).

2. Characterization of potential direct utilization sites (i.e., those sites with temperatures greater than 10°C above mean ambient surface temperatures) which can provide electrical offset.

3. Review of federal, state, and local legal, institutional, and environmental facilities which impact resource assessment and development.

4. Ranking of the sites based on developability and economics.

To accomplish the above, state agencies were assigned the lead on the task for which they possessed the greatest level of expertise.

The four state Assessment Team which was thus established began its work by identifying all potential geothermal sites in the region from existing literature. A total of 1,265 potential sites were identified by the presence of thermal and mineral springs or wells and/or areas of recent volcanic activity and high heat flow. These 1,265 sites were then screened to eliminate those which had little or no chance of providing either electrical generation and/or electrical offset through direct utilization. Sites were eliminated from further study due to inadequacies of resource temperatures, legal prohibitions against development, or inadequate electrical offset potential within economical transmission distances of a direct utilization site. Two hundred and fifty of the original 1,265 sites were determined to warrant further study.

Once the 250 sites had been selected, detailed information on location, ownership, leasing, water rights, geology, geochemistry, geophysical, drilling and special legal, institutional and environmental factors were collected and fully referenced for each site. This information has been entered into a computerized data base. This data base is stored on an IBM PC compatible microcomputer system using the R:BASE* 4000 relational database management system. This information formed the basis for all subsequent analyses including the determination of resource potential, developability, cost and finally the ranking of all sites capable of generating electricity or offsetting electrical demand.

The geothermal data base and associated reference list established as a result of this study are by far the most comprehensive ever assembled for this region and are designed to be easily updateable with new information. The data base can be expected to be the foundation upon which future studies, analyses, and decisions are made. In addition, the data base is structured so that inputs for any analysis tools developed during the course of this study can be readily obtained.

In compiling the data, it quickly became clear to the Team that very little detailed assessment data were available for most sites in the region. Tables 7.1 through 7.10 in Chapter 7 show that most resource sites have received only limited evaluation. This lack of data makes accurate determination of resource potential almost impossible, however, the methodologies developed by the USGS and described in detail in USGS Circular 726, 790, and 892 allow us to make reasonable estimates of electrical generation or electrical offsets.

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Estimates made by the Assessment Team using the USGS methodology clearly indicate that the regional geothermal potential could provide several thousand megawatts of energy over a minimum of thirty years.

The ability to develop significant amounts of the identified potential is often as dependent upon legal, institutional and legal factors as upon favorable geological parameters. Due to this, a thorough review and analysis of the legal and institutional framework for geothermal development in the four states was undertaken by the Assessment Team (Chapter 4). The Team also made a thorough analysis of environmental laws and potential impact upon the environment that geothermal exploration/development could be expected to have (Chapter 5).

The results of the legal and institutional analysis indicate that several problem areas need to be addressed. These include:

- Resource definition, characterization and ownership,
- Resource access through competitive or noncompetitive leasing,
- Groundwater law, and
- Utility regulations (especially related to district heating.)
- The most serious institutional problem appears to be the length of the primary lease term and provisions for extension (see section 4.2.7).

The environmental analysis indicates that potentially the most serious concerns are:

- Airborne effluents such as boron and radon
- Land subsidence
- Water supply and
- Protection of cultural sites.

Our analysis also indicates that other initial concerns such as H_2S emissions, water pollution, induced seismisity, noise, land use, and effects upon vegetation and wildlife have been less severe than originally anticipated or that mitigation measures are available to provide adequate environmental protection.

Once all available resource, legal, institutional, and environmental data were collected, it was necessary to develop a sound methodology which would allow for the incorporation of as much of the data as possible into a site-specific ranking procedure.

Because there is a strong relationship between a geothermal resource, its quality, and the legal, institutional, and environmental factors which determine its developability, the Assessment Team needed to develop a ranking procedure which would be equally sensitive to these areas. Sites needed to be ranked on a basis of developability and cost (Chapters 6, 8, 10).

The developability index used for ranking incorporates resource, engineering, legal, institutional, and environmental parameters based on a weighted variable evaluation of resource favorability. Cost was determined by engineering and economic data developed for the Assessment Team by Bechtel National, Inc., and the Oregon Institute of Technology Geological Heat Center.

On the basis of the developability index, 78 high temperature sites and 120 direct utilization sites were ranked as having "good" or "average" potential for development.

On the basis of cost, at least 29 of the high temperature sites appear to be technically capable of supporting a minimum total of total of at least 1,000 MW of electrical generation which could be competitive with the bus bar cost of conventional thermal generating technologies. Another 60 direct utilization sites have a minimum total energy potential of 900+ MW and can be expected to provide substantial amounts of electrical offset at or below present conventional energy prices.

Finally, the Assessment Team examined the sensitivity of the levelized cost of geothermal power to changes in key assumptions used in the analyses. The findings of the sensitivity analysis suggest that the manner in which fuel costs are treated is the single most sensitive factor affecting the levelized cost of energy, and is a direct reflection of the difference between single party field/plant development and ownership and two party arrangements where a utility purchases steam from a field developer. The results

indicate that a more thorough evaluation of owner relationships (together with other uncertainties) should be modeled using Monte Carlo probability techniques so as to more fully measure the effects which these factors have on the levelized cost of the produced or offset power.

Given the results of the present study and the developable potential, geothermal energy should be expected to play a major role in providing electrical offset as well as future generation when the need arises. We are unfortunately unable to say that this will be the case. Legal and institutional problems (presently compounded by an energy surplus) continue to discourage investment of time and money in geothermal exploration and development. Environmental concerns and misunderstandings often create costly delays in exploration and development work. Finally, a lack of basic information about the quality and extent of geothermal resource continues to discourage regional energy planners from committing to the development of this resource and including substantial amounts of geothermal energy in long range energy forecasts.

What then can be done to ensure that a significant portion of the geothermal potential that has been identified will be made available when needed? The following recommendations could provide many of the answers:

- A thorough evaluation of marketing opportunities and enabling factors should be undertaken as a way to encourage accelerated industry activity in exploration in the region.

- A detailed analysis of geothermal resource characterization and demonstration alternatives should be conducted to provide the region with the most economical assurance of geothermal being available when required.

- A detailed review and analysis of economic sensitivities of development/ownership Scenarios should be initiated.

- The regional data base, established under the four-state program, should be maintained and regularly updated to provide regional energy planners with the best possible information upon which to base future policy and acquisition decisions.

- Ongoing developments in conversion technology which are taking place in Nevada, California and Utah should be carefully monitored so that the most efficient technologies can be applied to future regional geothermal development.

- Priority should be given to removing federal, state, and local legal and institutional barriers to geothermal leasing, exploration, and utilization.

- Base line environmental data should be compiled for the most promising geothermal sites. These sites should represent a cross section of environments where extensive geothermal energy development can be expected to occur so as to provide the keys to environmentally acceptable development.

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CORRECTIONS

Page 15 - Reed, 1982 should read Reed, 1983a.

Page 90 - Renwick and Lewis, 1977 should read Renwick and Ried, 1976.

Page 197 - Figure 6.42 should read Direct Utilization Resource Ranking Data (Continued).

Page 357 - Black, et al., 1982 should read Black, et al., 1983.

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EXHIBIT I

MASTER LIST OF GEOTHERMAL RESOURCE SITES - IDAHO

The sites are organized by county.

A site is a well or spring which exhibits geothermal influence, or an area displaying recent volcanic activity and high heat flow.

MASTER LIST OF GEOTHERMAL RESOURCE SITES - IDAHO

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Ada	Lillie Collias Well	1N	1E 1	AD	25
	Nicholson Well	1N	1E 25	DB	25
	Agri-Con Well #4	1N	1E 36	AA	22
	IDU Land and Beef	1N	2E 6	AB	25
	Tom Bevins Well	2N	1E 22	DD	31
	George Whitmore Well	2N	1E 24	DA	27
	Warren Tozer Well	2N	3E 10	BC	20
	St. Trans. Dept. Well	2N	3E 28	CA	22
	Ferd Koch Well	3N	2E 2	CB	49
	Idaho State Capitol Well	3N	2E 10	AB	40
	Old Boise Hotel Well	3N	2E 10	AB	44
	Beard Well	3N	2E 11	AB	76
	BSU #2	3N	3E 11	BA	78
	BSU #2	3N	2E 11	BAC	74
	Warm Springs Water Dist.	3N	2E 12	CD	75
	Warm Springs Water Dist.	3N	2E 12	CD	77
	Old Penitentiary Well #1	3N	2E 13	AC	59
	Boise Water Corp. Well	3N	2E 36	AB	21
	Dennis Flake Well	4N	1E 24	DC	27
	Carl Rush Well	4N	2E 4	BD	29
	Hunt Brothers Floral #1	4N	2E 28	CB	47
	Hunt Brothers Floral #2	4N	2E 29	AC	47
	Hunt Brothers Floral #3	4N	2E 29	DA	43
	Edwards Greenhouse Well	4N	2E 29	AC	47
	John Boehm Well	5N	1E 25	AC	20
	Shadow Valley Well	5N	1E 25	BC	28
	D. McArthur Well	5N	1E 26	CD	23
	Ben Stadler Well	5N	1E 26	DC	29
	John Burgess Well	5N	1E 29	DA	22
	Julius Jeker Well #1	5N	1E 35	AC	40
	Julius Jeker Well #2	5N	1E 36	BD	24
	Jerry Davis Well #1	1N	1W 7	AC	21
	Clater Forsgren Well	1N	1W 7	BC	20
	Irvin Boehlke Well	1N	1W 15	DA	23
	Shane Bues Well	1N	1W 15	DA	23
	Terry Tlucek Well #1	1N	1W 22	DD	23
	John Cooknell Well	2N	1E 21	DD	23
	Tom Bevans Well	2N	1E 22	DD	24
	Kenneth Forrey Well #1	2N	1W 34	CD	20
	Kenneth Forrey Well #2	2N	1W 34	DA	20
	Sam Gabiola Well #1	2N	1W 35	CA	25
	Sam Gabiola Well #2	2N	1W 35	DD	22
	Bischof Realty Well	3N	1W 25	AD	21
	Letha Fisher Well	5N	1W 16	CA	20
	Harry Charters Well	1S	1W 5	AB	26
	Inital Butte Well	1S	1W 36	BB	23
Adams	Crab and Thompson Well	16N	1W 11	AC	22
	Bill Kampeter Well	16N	1W 15	BA	22

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Adams (Continued)	White Licks H.S.	16N	2E	33	BC	65
	Krigbaum H.S.	19N	2E	22	CC	43
	Zim's Resort	20N	1E	26	DD	65
	Stinky W.S.	21N	1E	23	AB	30
	Boulder Creek Resort	22N	1E	34	DA	26
	Starkey H.S.	18N	1W	34	DB	56
Bannock	Well	5S	34E	25	BD	32
	Gerald Johnson Well	5S	34E	25	CB	27
	Shoal Subdivision Well	5S	34E	26	DB	26
	Robert Brown Well #1	5S	34E	26	DA	41
	Robert Borwn Well #2	5S	34E	26	DB	25
	Gwinn Sigmain Well	5S	34E	26	DC	20
	Tadpole W.S.	5S	34E	27	AD	20
	Floyd Peterson Well	5S	34E	35	BA	20
	Dean Morris Well	9S	36E	3	CD	22
	Lava H.S.	9S	38E	21	DD	45
	Lava H.S.	9S	34E	22	CC	45
	Downata H.S.	12S	37E	12	CC	43
Bear Lake	Pescadero W.S.	11S	43E	36	BD	26
	Bear Lake H.S.	15S	44E	13	CC	48
Bingham	Yandell Springs	3S	37E	31	DB	32
	Alkali Flat W.S.	4S	38E	28	DD	34
Blaine	Hailey H.S.	2N	18E	18	DB	59
	Clarendon H.S.	3N	17E	27	DC	47
	Guyer H.S.	4N	17E	15	AA	71
	Warfield H.S.	4N	17E	31	BB	62
	Easley H.S.	5N	16E	10	DB	37
	Russian John H.S.	6N	16E	33	CC	35
	Magic H.S. Landing Well	1S	17E	23	AA	71
	Magic H.S. Landing Well	1S	17E	23	AA	72
	Condie H.S.	1S	21E	14	DD	52
	Milford Sweat H.S.	1S	22E	1	DA	44
Boise	Twin Springs	4N	6E	24	BC	67
	Stope Warm Springs	6N	5E	33	AB	40
	Warm Springs Resort	6N	5E	33	AD	42
	Danskin Creek H.S.	8N	5E	1	BC	40
	Hot Springs Campground	8N	5E	6	DC	48
	Donlay Ranch H.S.	8N	5E	10	BD	55
	Deer H.S.	9N	3E	25	BA	80
	Kirkham H.S.	9N	8E	32	CA	65
	Bonneville H.S.	10N	10E	31	BC	85

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Bonneville	Fall Creek Mineral Spring	1N 43E 9 CB	25
	Richard Piggot Well	2N 39E AD 30	
	Brockman Creek W.S.	2S 42E 26 DC	35
	Alpine W.S.	2S 46E 19 CA	37
Butte	Lewis Rothwell Well	3N 25E 32 CD	41
	Harvey Walker Well	3N 27E 9 AA	40
	Butte City Well	3N 27E 9 AB	35
	Big Southern Butte	4-6N 28-32E	**
Camas	Wardrop H.S.	1N 13E 32 AB	66
	Hot Springs Ranch	1N 13E 32 AB	60
	Hot Springs Ranch	1N 13E 32 AB	67
	Hot Springs Ranch	1N 13E 32 AB	64
	Elk Creek H.S.	1N 15E 14 AD	55
	Elk Creek H.S.	1N 15E 14 AD	55
	Elk Creek H.S.	1N 15E 14 AD	45
	Lightfoot H.S.	3N 13E 7 DC	56
	Baumgartner H.S.	3N 12E 7 DC	44
	Worswick H.S.	3N 14E 28 CA	81
	Sheep H.S.	1S 12E 16 CA	49
	Wolf H.S.	1S 12E 16 CB	45
	Keith Strom Well	1S 12E 31 CB	31
	Lee Barron Well #1	1S 13E 22 CC	26
	Lee Barron Well #2	1S 13E 27 CC	35
	Lee Barron Well #3	1S 13E 27 CC	45
	Barron H.S.	1S 13E 34 BC	72
	Lee Barron Well #4	1S 13E 34 BC	49
	Fairfield City Well	1S 14E 9 DA	21
Canyon	Leonard Tiegs Well #1	1N 2W 5 AD	22
	Don Tiegs Well #2	1N 2W 8 AC	22
	Melba City Well	1N 2W 36 CA	25
	John Tucker Well	2N 2W 9 BC	27
	Wesley Schober Well	2N 2W 34BD	48
	Cannon Farms Well #4	2N 3W 22 DC	30
	Idaho State School and Hospital	3N 2W 14 AD	20
	Nampa City Well #1	3N 2W 17 BC	25
	Nampa City Well #2	3N 2W 23 BC	31
	Simplot Feedlot Well	4N 3W 19 AD	40
	Caldwell Munc. Park Well	4N 3W 38 AA	28
	George Wright Well	4N 4W 4 DC	21
	Russell Fivecolt Well	4N 4W 5 DB	25
	Caldwell City Well	4N 3W 35 AB	20
	Parma City Well #1	5N 5W 4 DC	27
	Parma City Well #2	5N 5W 9 AD	20
	Parma Ice Well	5N 5W 9 CA	20
Caribou	Blackfoot River W.S.	5S 40E 14 BC	26
	Blackfoot Reservoir W.S.	6S 41E 1 AD	23

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Caribou (Continued)	Corral Creek Well #1	6S 41E 19 BA	42
	Corral Creek Well #2	6S 41E 19 BA	41
	Corral Creek Well #3	6S 41E 19 BA	41
	Corral Creek Well #4	6S 41E 19 BA	36
	Blackfoot Lava Field	4-7S 41-43E	**
	Portneuf River W.S.	7S 38E 26 CB	34
	Steamboat Springs Geyser	9S 41E 10 DA	31
	Soda Springs Geyser	9S 41E 12 AD	28
Cassia	Six S Ranch Well #1	11S 25E 11 CC	60
	Six S Ranch Well #2	11S 26E 20 DD	32
	Critchfield Well	11S 26E 28 BC	35
	C & Y Ranch Well #2	11S 27E 5 BA	29
	Lyle Durfee Well	13S 25E 22 BC	30
	Ward Springs	13S 26E 17 CC	21
	Ward Springs	14S 21E 34 BD	43
	Oakley H.S.	14S 22E 27 DC	47
	Sears Spring	14S 25E 6 BB	28
	Griffeth-Wight Well	14S 26E 1 BD	77
	Harold Wight Well	14S 26E 1 CD	63
	Harold Wight Well	14S 27E 18 CC	24
	Morris Mitchell Well #2	15S 21E 25 DC	46
	Harold Ward Well #2	15S 24E 22 DD	38
	BLM Well	15S 25E 29 CD	60
	BLM Well	15S 26E 12 AC	26
	BLM Well	15S 26E 22 DD	82
	Ivan Darrington Well #1	15S 26E 23 AA	85
	Frazier H.S. Well	15S 26E 23 BB	95
	Harriat Crank Well	15S 26E 23 DD	90
	Ivan Darrington Well #3	15S 26E 23 DD	33
	Reid Stewart Well	15S 26E 24 BA	32
	Ivan Darrington Well #4	15S 26E 24 DC	31
	BLM Well	15S 26E 25 AC	30
	BLM Well	16S 26E 5 BB	40
Clark	Lidy H.S. #1	9N 33E 2 BB	50
	Lidy H.S. Well	10N 33E 35 CC	59
	Warm Springs	11N 32E 25 AA	29
Custer	Bowery H.S.	7N 17E 6 AB	43
	Pierson H.S.	8N 14E 27 DB	60
	West Pass H.S.	8N 17E 32 BC	51
	Stanley H.S.	10N 13E 3 CA	41
	Slate Creek H.S.	10N 16E 30 BA	50
	Elkhorn H.S.	11N 13E 36 BA	57
	Basin Creek W.S.	11N 14E 21 DD	38
	Mormon Bend H.S.	11N 14E 29 AA	38
	Sunbeam H.S.	11N 15E 19 CA	76
	Robinson Bar H.S.	11N 15E 27 DD	49
	Sullivan H.S.	11N 17E 27 BD	41

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Custer (Continued)	Barney W.S.	11N	25E	23	CA	29
	Beardsley Hot Spring	14N	19E	23	DD	43
	Bill Johnston Well	14N	19E	34	DA	40
	Sunflower Flat H.S.	16N	12E	8	DD	43
	Thomas Creek Ranch H.S.	16N	12E	17	DA	43
	Lower Loon Creek H.S.	17N	14E	19	BD	49
Elmore	Charles Baker Well	3N	10E	10	AB	41
	Paradise H.S.	3N	10E	33	AC	53
	Paradise H.S. Well	3N	10E	33	BD	38
	Ninemeyer H.S.	5N	7E	24	BD	76
	Dutch Frank's H.S.	5N	9E	7	BB	65
	Atlanta H.S.	6N	11E	35	DA	38
	John Malota Well	2S	5E	23	BB	22
	Michael Jackson Well	3S	6E	24	DC	21
	Mountain Home City Well	3S	6E	26	AD	23
	Richard Chandler Well	4S	6E	35	BC	20
	Long Tom Ranch Well #1	3S	7E	1	AC	20
	Leslie Beam Well	3S	8E	36	CA	68
	Latty H.S.	3S	10E	31	DD	55
	Pete Nelson Well	4S	5E	19	AB	20
	Robert Bruce Well #1	4S	5E	25	BB	23
	Robert Bruce Well #2	4S	5E	26	AA	24
	Terry Peterman Well #1	4S	5E	26	CA	21
	Terry Peterman Well #2	4S	5E	36	CA	24
	Ralph Yrazabel Well	4S	7E	9	BB	24
	Beverly Olson Well	4S	7E	19	BD	26
	Northwest Pipeline Well	4S	8E	36	BB	38
	Bill Davis Well	4S	9E	8	AC	62
	Gary Lawson Well	5S	3E	14	CB	59
	Mike Wissel Well	5S	7E	16	AB	21
	Charles Boyd Well	5S	8E	23	BD	34
	Ray Thompson Well	5S	10E	25	AC	21
	Daniel Hatcher Well	5S	10E	28	BD	32
	Lloyd Knight Well	4S	10E	28	CA	30
	Magic West Co. Well	5S	10E	32	BD	38
	Charles Anderson Well	5S	11E	7	AC	32
	Robert Graham Well	5S	11E	19	CC	24
	Black Mesa Farm Well	6S	10E	12	CA	30
Franklin	Treasurton W.S. #1	12S	40E	36	AC	35
	Treasurton W.S. #2	12S	40E	36	AB	33
	Cleveland H.S. #1	12S	41E	31	CA	66
	Cleveland H.S. #2	12S	41E	31	CC	56
	Cleveland H.S. #3	12S	41E	31	CD	61
	Maple Grove H.S.	13S	41E	7	AC	78
	Maple Grove H.S.	13S	41E	7	AC	72
	Maple Grove H.S.	13S	41E	7	AC	60
	Ben Meek Well	14S	39E	36	AD	40
	Eldon Bingham Well	15S	39E	7	DB	63

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Franklin (Continued)	Battle Creek H.S.	15S	39E	8	BD	82
	Battle Creek H.S.	15S	39E	8	BD	43
	Battle Creek H.S.	15S	39E	8	BD	81
	Battle Creek H.S.	15S	39E	8	BD	84
	Squaw H.S. Well	15S	39E	17	BC	84
	Squaw H.S.	15S	39E	17	BD	69
	Squaw H.S.	15S	39E	17	BD	73
	Myron Fonnesbeck Well	16S	38E	24	AB	23
Fremont	Donald Trupp Well	7N	41E	25	CB	32
	Wayne Larsen Well	7N	41E	26	AC	22
	Henry Harris Well	7N	41E	34	AD	33
	Newdale City Well	7N	41E	34	32	
	Wallace Little Well	7N	41E	35	CD	36
	Claude Haws well	7N	41E	36	DD	32
	Dean Swindelman Well	7N	42E	8	CA	32
	Island Park Caldera	10-12N		40-45E		**
	Remington Produce Well	7N	42E	19	CC	26
	Ashton H.S.	9N	42E	23	DA	41
	Big Springs	14N	44E	34	BB	12
	Donald Jensen Well #1	6N	1W	26	AD	20
	Donald Jensen Well #2	6N	1W	26	AD	20
	Paul Crank Well	6N	2W	14	DB	24
Gem	Roystone H.S.	7N	1E	8	DD	55
	East Roystone H.S.	7N	1E	9	CD	45
Gooding	J. Shannon Well	4S	13E	28	AB	47
	White Arrow H.S.	4S	13E	30	AD	65
	Dave Archer Well	5S	12E	3	AA	57
Idaho	Burgdorf H.S.	22N	4E	1	BD	45
	Riggins H.S.	24N	2E	14	DB	42
	Barth H.S.	25N	12E	18	DD	61
	Red River H.S.	28N	10E	3	DD	55
	Weir Creek H.S.	36N	11E	13	BC	48
	Jerry Johnson H.S.	36N	13E	18	AD	48
Jefferson	Heise H.S.	4N	40E	25	DD	49
Jerome	Royal Catfish Industry	9S	17E	29	DB	43
Lemhi	Cronks Canyon H.S.	16N	21E	18	AD	46
	Salmon H.S.	20N	22E	3	AB	45
	Sharkey H.S.	20N	24E	34	CC	52
	Big Creek H.S.	23N	18E	22	CA	93
Madison	Lavere Ricks Well	5N	40E	5	CB	21
	Mark Ricks Well	5N	40E	8	BC	26
	Pauline Smith Well	5N	40E	9	CC	21

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Madison (Continued)	Green Canyon H.S.	5N 43E 6 BC	44
	Walz Enter., Inc. Well	6N 41E 10 AC	26
	Wanda Wood Well #1	6N 41E 10 BB	24
	Wanda Wood Well #2	6N 41E 10 DB	27
	Rexburg Caldera	4-8N 40-43E	**
Minidoka	Paul City Well	9S 23E 28 CC	22
Nez Perce	Lewiston City Well	35N 5W 6 CB	20
Oneida	Kent H.S.	12S 34E 36 BC	24
	Malad W.S.	14S 36E 27 CD	25
	Pleasantview W.S.	15S 35E 3 AA	25
	Woodruff H.S.	16S 36E 10 BB	27
Owyhee	Givens H.S.	1N 3W 21 BB	49
	Wesley Higgins Well	1N 4W 12 DB	36
	Earl Foote Well	1S 2W 7 CC	46
	Homedale City Well #1	3N 5W 4 DA	20
	Homedale City Well #2	3N 5W 0 AA	23
	George Johnston Well	3N 5W 28 CB	21
	Justamere Farms Well #1	3N 5W 30 AA	20
	Justamere Farms Well #2	3N 5W 30 AD	21
	Alfred Heywood Well	3S 1E 35 DA	20
	William Cox Well #1	4S 1E 25 CC	30
	William Cox Well #2	4S 1E 26 AB	27
	T. Adcock Well	4S 1E 29 CC	70
	George King Well	4S 1E 34 BA	75
	G. Christensen Well	4S 2E 29 DB	28
	R. Ketterling Well	4S 2E 32 BC	43
	C. Steiner Well	5S 1E 3 AA	32
	E. Lawrence Well #1	5S 1E 10 BD	64
	E. Johnston Well #2	5S 1E 21 CB	65
	E. Lawrence Well #2	5S 1E 24 AC	65
	E. Lawrence Well #3	5S 1E 24 AD	66
	Oscar Fields Well	5S 2E 1 BB	50
	Clarence Hopkins Well	5S 2E 2 CD	37
	Cox and Lawrence Well	5S 2E 5 BC	43
	H. Driskell Well #1	5S 2E 13 AD	23
	N. McKeeth Well	5S 3E 20 AD	60
	Burghardt Co. Well	5S 3E 20 BB	27
	Harald Simper Well #1	5S 3E 21 BB	22
	Harald Simper Well #2	5S 3E 21 BC	27
	Leroy Beaman Well	5S 3E 22 AA	25
	Cook's Greenhouse Well	5S 3E 26 BC	83
	Cook's Greenhouse Well	5S 3E 26 BC	67
	D. Bybee Well #1	5S 3E 27 BD	60
	A. Whitted Well	5S 3E 28 BC	65
	D. Bybee Well #2	5S 3E 35 CC	72
	Idaho Power Co. Well	5S 4E 34 CC	27

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Owyhee (Continued)	Chester Tindall Well	5S	5E	33	BB	22
	Clay Atkins Well	5S	5E	34	DD	25
	Lower Birch Spring	6S	1E	32	BB	25
	L. Post Well #1	6S	3E	2	BB	62
	L. Post Well #2	6S	3E	2	CC	53
	W. Bunt Well	6S	3E	4	BC	48
	J. Agenbroad Well	6S	3E	5	CA	61
	Nielson & Carothers Well	6S	3E	9	AC	39
	Triangle Dairy Well #1	6S	3E	11	DA	34
	Little Valley Irr. Well	6S	4E	14	AB	54
	Kent Kohring Well #1	6S	4E	25	BC	20
	Dick Ward Well	6S	4E	35	CD	33
	Colyer Cattle Co. Well	6S	5E	10	DD	39
	J.R. Simplot Well #1	6S	5E	18	CC	27
	J.R. Simplot Well #2	6S	5E	20	AA	44
	George Hutchinson Well	6S	5E	24	BC	34
	Bruneau City Well	6S	5E	24	DD	33
	Don Davis Well #1	6S	5E	29	DC	33
	Carl & Harry Loos Well	6S	5E	35	CC	22
	Idaho Parks Dept. Well	6S	6E	12	CC	37
	Mildred Bachman Well	6S	6E	19	CC	38
	Bruneau Cemetary Well	6S	6E	19	DB	42
	Ace Black Well	6S	6E	32	BD	35
	Wilbur Wilson Well #1	6S	7E	1	AC	41
	Wilbur Wilson Well #2	6S	7E	1	DB	33
	Carl Johnson Well	6S	7E	2	CD	35
	Sand Dunes Farms Well	6S	7E	8	BB	23
	Bill Burghardt Well #2	7S	3E	4	AC	34
	Keith Thomas Well	7S	4E	1	AC	40
	Pete Merrick Well #1	7S	4E	3	AB	42
	Pete Merrick Well #2	7S	4E	10	BD	38
	Frank Millett Well #1	7S	4E	11	CB	36
	Faria Brothers Well	7S	4E	12	BD	43
	Clarence Cook Well	7S	4E	13	BC	39
	Dave Lathinen Well	7S	4E	13	DC	40
	Frank Millett Well #2	7S	4E	14	AB	39
	Robert Black Well	7S	4E	15	AC	33
	Blaine Rawlins Well #3	7S	4E	23	CB	39
	Bell Brand Ranches Well	7S	4E	25	AD	37
	Gutheries Ranch Well	7S	4E	26	BC	31
	Dave Lathinen Well	7S	4E	27	BC	27
	Ace Black Well #2	7S	5E	5	DB	32
	Davis Brothers Well #1	7S	5E	7	AB	39
	Davis Brothers Well #2	7S	5E	8	CC	40
	Harry Loos Well	7S	5E	9	DD	40
	Roy Davis Well #2	7S	5E	13	AC	25
	Carl Steiner Well	7S	5E	13	CB	36
	Robert Tindall Well	7S	5E	16	AC	40
	Bell Brand, Inc. Well	7S	5E	19	CC	37
	Gene Tindall Well	7S	5E	28	AC	34

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Owyhee (Continued)	George Turner Well	7S	6E	7	AA	25
	Colyer Cattle Well #3	7S	6E	9	BA	51
	R.L. Owens Well #2	7S	6E	16	CD	43
	Hot Springs Ranch Well	7S	6E	21	DB	43
	R. L. Owens Well #4	7S	6E	23	BB	47
	Rose Williams Well	7S	6E	23	CA	44
	R.L. Owens Well #7	7S	6E	26	AD	38
	James Prescott Well	7S	6E	27	AD	43
	Jean Prescott H.S.	7S	6E	34	DC	41
	Prescott W.S.	7S	6E	35	BB	40
	Indian Bathtub H.S.	8S	6E	3	BD	39
	Indian H.S.	12S	7E	33	C	69
	Murphy H.S.	16S	9E	24	BB	51
Payette	James Mosier Well	8N	4W	7	CC	20
	Lee Reed Well	9N	5W	35	AB	20
Power	Idaho Power Company Well	7S	31E	31	AD	24
	Max Mayer Well	8S	31E	17	AB	25
	Fred Mayer Well	8S	31E	17	BD	26
	Indian Springs	8S	31E	18	DA	32
	Rockland Warm Springs	10S	30#	13	CD	38
Twin Falls	Bill Sliger Well	8S	14E	30	AC	63
	Miracle H.S.	8S	14E	31	AC	54
	Harry Huttanus Well #2	8S	14E	33	CB	59
	Ed Kerpa Well	9S	14E	9	AD	31
	Wright Fuel Company Well	9S	14E	24	BC	24
	Buhl City Well #1	9S	14E	36	DA	30
	Green Giant Canning Well	9S	15E	31	CB	20
	Buhl City Well #2	9S	15E	31	CC	32
	Filer City Well	10S	16E	8	CD	27
	U.S. Steel-Hansen Plant	10S	18E	26	BB	20
	Twin Falls Canal Company Well	10S	18E	14	CC	29
	Sam High and Sons Well	11S	19E	33	DD	33
	T. Sturgill Well	11S	20E	34	CC	32
	T. Sturgill Well	12S	17E	6	CB	37
	Nat-SOO-PAH W.S.	12S	17E	31	BA	36
	Idaho State Well	12S	18E	1	BB	38
	Hollister Village Well	13S	17E	7	BA	35
	Magic H.S.	16S	17E	30	AC	46
Valley	Boiling Springs	12N	5E	22	BB	85
	Silver Creek Plunge	12N	5E	36	DB	39
	Belvidere H.S.	13N	3E	13	AA	44
	Cabarton H.S.	13N	4E	31	CA	71
	Cascade City Well	14N	3E	36	AB	42
	Volcan H.S.	14N	6E	11	BD	87
	Arling W.S.	15N	3E	13	BB	34
	Molly's H.S.	15N	6E	14	AB	59

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Valley (Continued)	South Fork Plunge	15N	6E	14	CD	55
	Pistol Creek H.S.	16N	10E	14	DB	46
	Sunflower Plat H.S.	16N	12E	15	BB	65
	Riverside H.S.	16N	12E	16	CB	43
	Holdover H.S.	17N	6E	2	BA	46
	Kwiskwis H.S.	17N	10E	11	BB	69
	Mid Fork Indian Creek H.S.	17N	11E	16	AC	72
	Indian Creek H.S.	17N	11E	21	B	88
	Cox H.S.	17N	13E	27	AA	55
	Teapot H.S.	18N	6E	9	AD	60
	Hot Creek W.S.	18N	8E	17	BD	35
Washington	Cove Creek H.S.	10N	3W	9	CC	74
	Elvin Craig Well	11N	2W	16	AA	41
	Crane Creek H.S.	11N	3W	7	BD	92
	Crane Creek H.S.	11N	3W	7	BD	57
	Douglas McGinnis Well	11N	5W	20	BD	21
	Glenn Hill Well	11N	6W	3	DB	24
	Glenn Hill Well	11N	6W	3	DC	25
	Weiser H.S.	11N	6W	10	AC	22
	Geosolar Growers Well #1	11N	6W	10	CC	78
	Geosolar Growers Well #2	11N	6W	10	CC	77
	Geosolar Growers Well #3	13N	6W	10	CC	70
	Midvale City Well	13N	3W	8	CC	28
	Fairchild Lumber Co. Well	13N	4W	13	BA	29
	Lakey H.S.	14N	2W	6	BB	70
	Cambridge City Well	14N	3W	3	DD	26
	Fairchild H.S.	14N	3W	19	CB	50

** - Denotes recent volcanic activity in areas with high heat flow

LIST OF SCREENED GEOTHERMAL RESOURCES SITES - IDAHO

I. **Sites in Legally-Designated Areas**
Includes: National Parks, National Monuments, and Wilderness Areas

II. **Sites With Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites With Volcanics Older Than That of a Favorable Site**
Explanation: The sites listed in this section have a maximum geothermometer of greater than 90°C listed in the literature; however, all sites with geothermometers greater than 90°C were evaluated using the chemical concentrations also listed in the literature. A most likely reservoir temperature was determined for the sites in this section of less than 90°C.

To determine favorable volcanic sites, a table was used to screen sites according to volcanic rock age and composition.

Composition	Max. Age (10^3 Years)	
Basalt	Greater than	40
Andesite	Greater than	100
Rhyolite	Greater than	1,000

III. **Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature**
Exception: Excluding sites with a geothermometer of greater than or equal to 90°C.

IV. **Sites Failing Population/Distance Requirements**
Explanation: For direct use applications the "site" is the point of end use and the well or spring is the geothermal resource.

Screen: Sites with Population:	
1-100	Resource is on site
101-1,000	Resource is within 2 km
1,001-10,000	Resource is within 8 km
10,001-100,000	Resource is within 20 km
100,001+	Resource is within 40 km

I. Idaho Sites in Legally-Designated Areas

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
-- No Sites --			

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C or Volcanic Sites With Volcanics Older Than That of a Favorable Site - Idaho

COUNTY	SITE	LOCATION (T,R,S)		MEASURED TEMP. (°C)
Camas	Wardrop Hot Springs	1N	13E	45

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature - Idaho

COUNTY	SITE	LOCATION (T,R,S)		MEASURED TEMP. (°C)
Nez Perce	Lewiston City Well	35N	5W	20

IV. Idaho Sites Failing Population/Distance Requirements

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Ada	Lillie Collias Well	1N	1E	1	AD	25
	Nicholson Well	1N	1E	25	DA	25
	Agri-Con Well #4	1N	1E	36	AA	22
	IDU Land and Beef	1N	2E	6	AB	25
	Jerry Davis Well #1	1N	1W	7	AC	21
	Clater Forsgren Well	1N	1W	7	BC	20
	Irvin Boehlke Well	1N	1W	8	DB	22
	Shane Bues Well	1N	1W	15	DA	23
	Terry Tlucek Well #1	1N	1W	22	DD	23
	Letha Fisher Well	5N	1W	16	CA	20
	Harry Charters Well	1S	1W	5	AB	26
	Inital Butte Well	1S	1W	36	BB	23
Adams	Zim's Resort	20N	1E	26	DD	65
	Stinky W.S.	21N	1E	23	AB	30
	Boulder Creek Resort	22N	1E	34	DA	26
	Starkey H.S.	18N	1W	34	DB	56
Bannock	Dean Morris Well	9S	36E	3	CD	22
	Downata H.S.	12S	37E	12	CC	43
Bear Lake	Pescadero W.S.	11S	43E	36	BD	26
	Bear Lake H.S.	15S	44E	13	CC	48
Bingham	Yandell Springs	3S	37E	31	DB	32
	Alkali Flat W.S.	4S	38E	28	DD	34
Blaine	Clarendon H.S.	3N	17E	27	DC	47
	Easley H.S.	5N	16E	10	DB	37
	Russian John H.S.	6N	16E	33	CC	35
	Condie H.S.	1S	221E	14	DD	53
	Milford Sweat H.S.	1S	22E	1	DA	44
Boise	Twin Springs	4N	6E	24	BC	67
	Danskin Creek H.S.	8N	5E	1	BC	40
	Hot Springs Campground	8N	5E	6	DC	48
	Donlay Ranch H.S.	8N	5E	10	BD	55
	Kirkham H.S.	9N	8E	32	CA	65
Bonneville	Fall Creek Mineral Spring	1N	43E	9	CB	25
	Brockman Creek W.S.	2S	42E	26	DC	35
	Alpine W.S.	2S	46E	19	CA	37
Butte	Lewis Rothwell Well	3N	25E	32	CD	41
Camas	Hot Springs Ranch	1N	13E	32	AB	60
	Hot Springs Ranch	1N	13E	32	AB	67
	Hot Springs Ranch	1N	13E	32	AB	64
	Elk Creek H.S.	1N	15E	14	AD	55
	Elk Creek H.S.	1N	15E	14	AD	55

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Camas (Continued)	Elk Creek H.S.	1N	15E	14	AB	45
	Lightfoot H.S.	3N	13E	7	DC	56
	Baumgartner H.S.	3N	12E	7	DC	44
	Sheep H.S.	1S	12E	16	CA	49
	Wolf H.S.	1S	12E	16	CB	45
	Keith Strom Well	1S	12E	31	CB	31
	Lee Barron Well #1	1S	13E	33	CC	26
	Lee Barron Well #2	1S	13E	27	CC	35
	Lee Barron Well #3	1S	13E	27	CC	45
	Lee Barron Well #4	1S	13E	34	BC	49
Canyon	Leonard Tiegs Well #1	1N	2W	5	AD	22
	Don Tiegs Well #2	1N	2W	8	AC	22
	Wesley Schober Well	2N	2W	34	BD	48
	Cannon Farms Well #4	2N	3W	22	DC	30
	Caldwell Munc. Park Well	4N	3W	38	AA	28
Caribou	Blackfoot River W.S.	5S	40E	14	BC	26
	Blackfoot Reservoir W.S.	6S	41E	1	AD	23
	Corral Creek Well #1	6S	41E	19	BA	42
	Corral Creek Well #2	6S	41E	19	BA	41
	Corral Creek Well #3	6S	41E	19	BA	41
	Corral Creek Well #4	6S	41E	19	BA	36
	Portneuf River W.S.	7S	38E	26	CB	34
Cassia	Six S Ranch Well #1	11S	25E	11	CC	60
	Six S Ranch Well #2	11S	26E	20	DD	32
	Critchfield Well	11S	26E	28	BC	35
	C & Y Ranch Well #2	11S	27E	5	BA	29
	Lyle Durfee Well	13S	25E	22	BC	30
	Ward Springs	13S	26E	17	CC	21
		14S	21E	34	BD	43
	Oakley H.S.	14S	22E	27	DC	47
	Sears Spring	14S	25E	6	BB	28
	Griffeth-Wight Well	14S	26E	1	BD	77
	Harold Wight Well	14S	26E	1	CD	63
	Harold Ward Well	14S	27E	18	CC	24
	Morris Mitchell Well #2	15S	21E	25	DC	46
	Harold Ward Well #2	15S	24E	22	DD	38
	BLM Well	15S	25E	29	CD	60
	BLM Well	15S	26E	12	AC	26
	Ivan Darrington Well #3	15S	26E	23	DD	33
	Reid Stewart Well	15S	26E	24	BA	32
	Ivan Darrington Well #4	15S	26E	24	DC	31
	BLM Well	15S	26E	25	AC	30
	BLM Well	16S	26E	5	BB	40
Clark	Lidy H.S. #1	9N	33E	2	BB	50
	Lidy H.S. Well	10N	33E	35	CC	59
	Warm Springs	11N	32E	25	AA	29

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Custer	Bowery H.S.	7N	17E	6	AB	43
	Pierson H.S.	8N	14E	27	DB	60
	West Pass H.S.	8N	17E	32	BC	51
	Slate Creek H.S.	10N	16E	30	BA	50
	Elkhorn H.S.	11N	13E	36	BA	57
	Basin Creek w.S.	11N	14E	21	DD	38
	Mormon Bend H.S.	11N	14E	29	AA	38
	Sunbeam H.S.	11N	15E	19	CA	76
	Robinson Bar H.S.	11N	15E	27	DD	49
	Sullivan H.S.	11N	17E	27	BD	41
	Barney W.S.	11N	25E	23	CA	29
	Sunflower Flat H.S.	16N	12E	8	DD	43
	Thomas Creek Ranch H.S.	16N	12E	17	DA	43
	Lower Loon Creek H.S.	17N	14E	19	BD	49
Elmore	Charles Baker Well	3N	10E	10	AB	41
	Paradise H.S.	3N	10E	33	AC	53
	Paradise H.S. Well	3N	10E	33	BD	38
	Ninemeyer H.S.	5N	7E	24	BD	76
	Dutch Frank's H.S.	5N	9E	7	BB	65
	Atlanta H.S.	6N	11E	35	DA	38
	John Malota Well	2S	5E	23	BB	22
	Leslie Beam Well	3S	8E	36	CA	68
	Beverly Olson Well	4S	7E	19	BD	26
	Northwest Pipeline Well	4S	8E	36	BB	38
	Bill Davis Well	4S	9E	8	AC	62
	Gary Lawson Well	5S	3E	14	CB	59
	Mike Wissel Well	5S	7E	16	AB	21
	Charles Boyd Well	5S	8E	23	BD	34
	Charles Anderson Well	5S	11E	7	AC	32
Franklin	Treasurton W.S. #1	12S	40E	36	AC	35
	Treasurton W.S. #2	12S	40E	36	AD	33
	Cleveland H.S. #1	12S	41E	31	CA	66
	Cleveland H.S. #2	12S	41E	31	CC	56
	Cleveland H.S. #3	12S	41E	31	CD	61
	Eldin Bingham Well	15S	39E	7	DB	63
	Myron Fonnesbeck Well	16S	38E	24	AB	23
Fremont	Donald Trupp Well	7N	41E	25	CB	32
	Wayne Larsen Well	7N	41E	26	AC	22
	Henry Harris Well	7N	41E	34	AD	33
	Newdale City Well	7N	41E	34	DC	32
	Wallace Little Well	7N	41E	35	CD	36
	Claude Haws Well	7N	41E	36	DD	32
	Dean Sindelman Well	7N	42E	8	CA	32
	Remington Produce Well	7N	42E	19	CC	26
	Big Springs	14N	44E	34	BB	12
Gooding	J. Shannon Well	4S	13E	28	AB	47

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Gooding (Continued)	Dave Archer Well	5S	12E	3	AA	57
Idaho	Burgdorf H.S.	22N	4E	1	BD	45
	Barth H.S.	25N	12D	18	DD	61
	Red River H.S.	28N	10E	3	DD	55
	Weir Creek H.S.	36N	11E	13	BC	48
	Jerry Johnson H.S.	36N	11E	18	AD	48
Jefferson	Heise H.S.	4N	40E	25	DD	49
Jerome	Royal Catfish Industry	9S	17E	29	DB	43
Lemhi	Cronks Canyon H.S.	16N	21E	18	AD	46
	Salmon H.S.	20N	22E	3	AB	45
Madison	Green Canyon H.S.	5N	43E	6	BC	44
	Walz Enter., Inc. Well	6N	41E	10	AC	26
	Wanda Wood Well #1	6N	41E	10	BB	24
	Wanda Wood Well #2	6N	41E	10	DB	27
Oneida	Kent H.S.	12S	34E	36	BC	24
	Pleasantview W.S.	15S	35E	3	AA	25
	Woodruff H.S.	16S	36E	10	BB	27
Owyhee	Givens H.S.	1N	3W	21	BB	49
	Wesley Higgins Well	1N	4W	12	DB	36
	Earl Foote Well	1S	2W	7	CC	46
	Alfred Heywood Well	3S	1E	35	DA	20
	William Cox Well #1	4S	1E	25	CC	30
	William Cox Well #2	4S	1E	26	AB	27
	T. Adcock Well	4S	1E	29	CC	70
	George King Well	4S	1E	34	BA	75
	G. Christensen Well	4S	2E	29	DB	28
	R. Ketterling Well	4S	2E	32	BC	43
	C. Steiner Well	5S	1E	3	AA	32
	E. Lawrence Well #1	5S	1E	10	BD	64
	E. Johnston Well #2	5S	1E	21	CB	65
	E. Lawrence Well #2	5S	1E	24	AC	65
	E. Lawrence Well #3	5S	1E	24	AD	66
	Oscar Fields Well	5S	2E	1	BB	50
	Clarence Hopkins Well	5S	2E	2	CD	37
	Cox and Lawrence Well	5S	2E	5	BC	43
	H. Driskell Well #1	5S	2E	13	AD	23
	Leroy Beaman Well	5S	3E	22	AA	25
	Cook's Greenhouse Well	5S	3E	26	BC	83
	Cook's Greenhouse Well	5S	3E	26	BC	67
	D. Bybee Well #1	5S	3E	27	BD	60
	A. Whitted Well	5S	3E	28	BC	65
	D. Bybee Well #2	5S	3E	35	CC	72

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Owyhee (Continued)	Idaho Power Co. Well	5S	4E	34	CC	27
	Chester Tindall Well	5S	5E	33	BB	22
	Clay Atkins Well	5S	5E	34	DD	25
	Lower Birch Spring	6S	1E	32	BB	25
	L. Post Well #1	6S	3E	2	BB	62
	L. Post Well #2	6S	3E	2	CC	53
	W. Bunt Well	6S	3E	4	BC	48
	J. Agenbroad Well	6S	3E	5	CA	61
	Nielson & Carothers Well	6S	3E	9	AC	39
	Triangle Dairy Well #1	6S	3E	11	DA	34
	Little Valley Irr. Well	6S	4E	14	AB	54
	Kent Kohring Well #1	6S	4E	25	BC	20
	Dick Ward Well	6S	4E	35	CD	33
	Colyer Cattle Co. Well	6S	5E	10	DD	39
	J.R. Simplot Well #1	6S	5E	18	CC	27
	J.R. Simplot Well #2	6S	5E	20	AA	44
	George Hutchinson Well	6S	5E	24	BC	34
	Bruneau City Well	6S	5E	24	DD	33
	Don Davis Well #1	6S	5E	29	DC	33
	Carl & Harry Loos Well	6S	5E	35	CC	22
	Idaho Parks Dept. Well	6S	6E	12	CC	37
	Mildred Bachman Well	6S	6E	19	CC	38
	Bruneau Cemetary Well	6S	6E	19	DB	42
	Ace Black Well	6S	6E	32	BD	35
	Wilbur Wilson Well #1	6S	7E	1	AC	41
	Wilbur Wilson Well #2	6S	7E	1	DB	33
	Carl Johnson Well	6S	7E	2	CD	35
	Sand Dunes Farms Well	6S	7E	8	BB	23
	Bill Burghardt Well #2	7S	3E	4	AC	34
	Keith Thomas Well	7S	4E	1	AC	40
	Pete Merrick Well #1	7S	4E	3	AB	42
	Pete Merrick Well #2	7S	4E	10	BD	38
	Frank Millett Well #1	7S	4E	11	CB	36
	Faria Brothers Well	7S	4E	12	BD	43
	Clarence Cook Well	7S	4E	13	BC	39
	Dave Lathinen Well	7S	4E	13	DC	40
	Frank Millett Well #2	7S	4E	14	AB	39
	Robert Black Well	7S	4E	15	AC	33
	Blaine Rawlins Well #3	7S	4E	23	CB	39
	Bell Brand Ranches Well	7S	4E	25	AD	37
	Gutheries Ranch Well	7S	4E	26	BC	31
	Dave Lathinen Well	7S	4E	27	BC	27
	Ace Black Well #2	7S	5E	5	DB	32
	Davis Brothers Well #1	7S	5E	7	AB	39
	Davis Brothers Well #2	7S	5E	8	CC	40
	Harry Loos Well	7S	5E	9	DD	40
	Roy Davis Well #2	7S	5E	13	AC	25
	Carl Steiner Well	7S	5E	13	CB	36
	Robert Tindall Well	7S	5E	16	AC	40
	Bell Brand, Inc. Well	7S	5E	19	CC	37

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Owyhee (continued)	Gene Tindall Well	7S	5E	28	AC	34
	George Turner Well	7S	6E	7	AA	25
	Colyer Cattle Well #3	7S	6E	9	BA	51
	R.L. Owens Well #2	7S	6E	16	CD	43
	Hot Springs Ranch Well	7S	6E	21	DB	43
	R. L. Owens Well #4	7S	6E	23	BB	47
	Rose Williams Well	7S	6E	23	CA	44
	R.L. Owens Well #7	7S	6E	26	AD	38
	James Prescott Well	7S	6E	27	AD	43
	Jean Prescott H.S.	7S	6E	34	DC	41
	Prescott W.S.	7S	6E	35	BB	40
	Indian Bathtub H.S.	8S	6E	3	BD	39
Power	Indian Springs	8S	31E	18	DA	32
	Rockland Warm Springs	10S	30#	13	CD	38
Twin Falls	Miracle H.S.	8S	14E	31	AC	54
	Harry Huttanus Well #2	8S	14E	33	CB	59
	Ed Kerpa Well	9S	14E	9	AD	31
	Sam High and Sons Well	11S	19E	33	DD	33
	T. Sturgill Well	11S	20E	34	CC	32
	T. Sturgill Well	12S	17E	6	CB	37
	Nat-SOO-PAH W.S.	12S	17E	31	BA	36
	Idaho State Well	12S	18E	1	BB	38
	Hollister Village Well	13S	17E	7	BA	35
	Magic H.S.	16S	17E	30	AC	46
Valley	Silver Creek Plunge	12N	5E	36	DB	39
	Arling W.S.	15N	3E	13	BB	34
	Molly's H.S.	15N	6E	14	AB	59
	South Fork Plunge	15N	6E	14	CD	55
	Pistol Creek H.S.	16N	10E	14	DB	46
	Sunflower Plat H.S.	16N	12E	15	BB	65
	Riverside H.S.	16N	12E	16	CB	43
	Holdover H.S.	17N	6E	2	BA	46
	Kwiskwis H.S.	17N	10E	11	BB	69
	Mid Fork Indian Creek H.S.	17N	11E	16	AC	72
	Indian Creek H.S.	17N	11E	21	B	88
	Cox H.S.	17N	13E	27	AA	55
	Teapot H.S.	18N	6E	9	AD	60
	Hot Creek W.S.	18N	8E	17	BD	35
Washington	Elvin Craig Well	11N	2W	16	AA	41
	Glenn Hill Well	11N	6W	3	DB	24
	Glenn Hill Well	11N	6W	3	DC	25
	Weiser H.S.	11N	6W	10	AC	22
	Geosolar Growers Well #1	11N	6W	10	CC	78
	Geosolar Growers Well #2	11N	6W	10	CC	77
	Geosolar Growers Well #3	13N	6W	10	CC	70
	Fairchild Lumber Co. Well	13N	4W	13	BA	28

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Washington (Continued)	Lakey H.S.	14N	2W	6	BB	70
	Cambridge City Well	14N	3W	3	DD	26
	Fairchild H.S.	14N	3W	19	CB	50

FINAL SITE LISTS - IDAHO

I. Electrical Generation Sites

An electrical generation site is a goethermal well or spring with a most likely geothermometer of greater than or equal to 90°C, or an area displaying recent volcanic activity and high heat flow. These sites have been screened.

II. Direct Utilization Sites

A direct utilization site is a point of end use, such as a city or town. A geothermal well or spring is considered the resource. These sites have been screened.

I. Electrical Generation Sites - Idaho

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Adams	White Licks Hot Springs	16N	2E	65.0	145
	Krigbaum Hot Springs	19N	2E	43.0	97
Blaine	Guyer Hot Springs	4N	17E	70.0	90
Boise	Deer Hot Springs	9N	3E	79.5	144
	Bonneville Hot Springs	10N	10E	85.0	132
Butte	Big Southern Butte			**	**
Camas	Magic Reservoir	1S	17E	70.5	175
	Barron's Hot Springs	1S	13E	45.0	125
	Worswick Hot Springs	3N	14E	87.0	100
Caribou	Blackfoot Lava Field			**	**
Cassia	Raft River	15S	26E	95.0	146
Custer	Sunbeam Hot Springs	11N	15E	76.0	111
Elmore	Latty Hot Springs	3S	10E	55.0	135
Franklin	Maple Grove Hot Springs	13S	41E	76.0	111
	Ben Meek Well	14S	39E	44.5	97
	Battle Creek Hot Springs	15S	39E	77.0	125
	Squaw Creek Hot Springs	15S	39E	73.0	150
Fremont	Island Park Caldera	10-12S	40-44E	**	**
Gem	Roystone Hot Springs	7N	1E	64.0	152
Gooding	White Arrow	4S	13E	65.0	135
Idaho	Riggins Hot Springs	24N	2E	41.0	98
Lemhi	Sharkey Hot Springs	20N	24E	63.5	175
	Owl Creek Hot Springs	23N	17E	51.0	162
	Big Creek Hot Springs	23N	18E	94.0	184
Madison	Rexburg Caldera			**	**
Owyhee	Indian Creek Hot Springs	12S	7E	87.0	102
	Murphy Hot Springs	16S	9E	55.0	113
Valley	Boiling Springs	12N	5E	86.0	101
	Cabarton Hot Springs	13N	4E	70.5	100
	Vulcan Hot Springs	14N	6E	87.0	100

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Washington	Cove Creek/Crane Creek H.S.	11N	3W	92.0	177

** - Denotes recent volcanic activity in areas with high heat flow

II. Direct Utilization Sites - Idaho

COUNTY	SITE	LOCATION (T,R,S)		POP.	MEASURED TEMP. (°C)
Ada	Boise	3N	2E	102,451	78
	Garden City	4N	2E	4,568	47
	Meridian	3N	1W	6,658	21
	Eagle	5N	1E	2,620	40
	Kuna	2N	1W	1,767	25
Adams	Council	16N	1W	917	22
Bannock	Chubbuck	5S	34E	7,052	41
	Pocatello	5S	34E	46,274	41
	Lava Hot Springs	9S	38E	467	45
Blaine	Hailey	2N	18E	2,109	55
	Ketchum	4N	17E	2,200	70
Boise	Idaho City	6N	5E	300	42
Bonneville	Idaho Falls	2N	39E	39,590	20
	Ammon	2N	39E	4,669	20
Butte	Butte City	3N	27E	93	40
Camas	Fairfield	1S	14E	404	21
Canyon	Caldwell	4N	3W	17,699	40
	Melba	1N	2W	276	24
	Nampa	3N	2W	25,112	31
	Parma	5N	5W	1,820	27
Caribou	Soda Springs	9S	41E	4,051	31
Custer	Challis	14N	19E	758	43
	Stanley	10N	13E	99	41
Elmore	Glenns Ferry	5S	10E	1,374	30
	Mountain Home	3S	6E	7,540	23
	Mountain Home AFB	4S	5E	9,975	20
Franklin	Preston	15S	39E	3,759	84
Fremont	Ashton	9N	42E	1,219	26
Gem	Emmett	6N	1W	4,605	27
Madison	Rexburg	5N	40E	11,559	26
Minidoka	Paul	9S	23E	940	22
Oneida	Malad City	14S	36E	1,915	25

COUNTY	SITE	LOCATION (T,R,S)		POP.	MEASURED TEMP. (°C)
Owyhee	Grand View	5S	3E	336	27
	Homedale	3N	5W	2,078	23
Payette	Payette	9N	5W	5,448	20
Power	American Falls	7S	31E	3,626	24
Twin Falls	Buhl	9S	14E	3,629	30
	Filer	10S	16E	1,645	27
	Hansen	10S	18E	1,078	20
	Kimberly	10S	17E	2,307	29
	Twin Falls	10S	17E	26,109	63
Valley	Cascade	14N	3E	945	42
Washington	Midvale	13N	3W	205	29
	Weiser	11N	5W	4,771	21

MASTER LIST OF GEOTHERMAL RESOURCE SITES - MONTANA

The sites are organized by county.

A site is a well or spring which exhibits geothermal influence, or an area displaying recent volcanic activity and high heat flow.

MASTER LIST OF GEOTHERMAL RESOURCE SITES - MONTANA

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Beaverhead	Anderson's Pasture Springs	13S	2W	18	26.0
	Apex Warm Spring	5S	9W	10	25.0
	Brown's Springs	8S	9W	30	23.8
	Elkhorn Hot Springs	4S	12W	29	48.5
	Jackson Spring	5S	15W	25	58.0
	Lovells Hot Spring	8S	9W	28	19.4
	McNenomay Ranch Spring	9S	10W	29	19.0
	Staudenmeyer Springs	13S	2W	17	28.0
	Uranium Test Well	2S	15W	14	15.5
Broadwater	Bedford Hot Spring	7N	1E	23	23.6
	Bruce Well	4N	1E	4	18.0
	Greyson Spring	6N	2E	21	17.9
	Hunsaker Spring	4N	2E	18	15.0
	Hunsaker Spring	4N	2E	32	24.5
	Plunkets Lake Warm Springs	4N	1E	27	16.5
	Toston Warm Springs	4N	3E	6	15.0
	Werner Warm Springs	5N	1E	22	18.0
Deer Lodge	Anaconda Hot Springs	4N	11W	13	21.7
	Gregson (Fairmont) Hot Springs	3N	10W	2	70.0
	Warm Springs	5N	10W	24	77.0
	Wendt Well	3 N	10W	11	24.0
Gallatin	Baker's Hole Well	13S	5E	15	16.0
	Bozeman Hot Springs	2S	4E	14	54.6
	Bridger Canyon Warm Spring	1S	6E	34	20.2
	Targhee Sulfur Warm Spring	13S	4E	27	18.0
Granite	Bearmouth Warm Springs 1	11N	14W	11	20.2
	Bearmouth Warm Springs 2	11N	14W	12	15.0
	Nimrod Springs	11N	15W	14	20.5
Jefferson	Alhambra Hot Springs	8N	3W	16	55.6
	Boulder Hot Springs	5N	4W	10	76.0
	Pipestone Hot Springs 1 & 2	2N	5W	28	57.0
Lake	Campaqua Well	22N	23W	29	50.0
Lewis & Clark	Broadwater Hot Spring	10N	4W	28	62.0
	Marysville Well	12N	8W	32	96.5
	Sun River Springs	22N	10W	26	30.4
Madison	Ennis Hot Springs	5S	1W	28	83.2
	New Biltmore Hot Springs	4S	7W	28	53.0
	Norris Hot Springs	3S	1W	14	52.5
	Potosi Warm Springs 1	3S	2W	7	49.5
	Potosi Warm Springs 2 and 3	3S	2W	15	37.0
	Pullers Hot Springs	8S	5W	1	44.0
	Renova Hot Springs	1N	4W	32	50.0

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Madison (Continued)	Silver Star Hot Springs	2S	6W	1	71.5
	Sloan Cow Camp Spring	12S	1E	19	29.5
	Trudau Warm Springs	7S	4W	7	22.7
	Vigilante Spring	9S	3W	22	23.5
	West Fork Swimming Hole	12S	1E	18	26.0
	Wolf Creek Hot Springs	10S	1E	9	68.0
Meagher	Ringling Well	7N	7E	25	48.0
	White Sulphur Springs	9N	7E	18	46.0
Missoula	Lolo Hot Springs	1N	23W	7	44.0
Park	Bear Creek Springs	9S	9E	19	24.0
	Carter's Bridge Warm Springs	3S	9E	1	28.0
	Chico Hot Springs	6S	8E	1	45.0
	La Duke (Corwin) Hot Spring	8S	8E	32	65.0
Powell	Avon Warm Springs	10N	8W	24	25.5
	Deer Lodge Prison Hot Springs	7N	10W	29	26.0
	Garrison Warm Springs	10N	9W	19	25.0
Ravalli	Blue Joint Hot Spring 1	2S	23W	1	28.8
	Blue Joint Hot Springs 2	2S	22W	6	29.4
	Florence Well	10N	20W	12	15.0
	Gallogly Spring	1S	19W	15	41.7
	Medicine Hot Springs	1N	20W	12	45.0
	Sleeping Child Hot Springs	4N	19W	7	52.0
Sanders	Camas Hot Springs	21N	24W	3	45.0
	Green Springs	20N	24W	33	18.9

LIST OF SCREENED GEOTHERMAL RESOURCES SITES - MONTANA

I. **Sites in Legally-Designated Areas**
Includes: National Parks, National Monuments, and Wilderness Areas

II. **Sites With Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites With Volcanics Older Than That of a Favorable Site**
Explanation: The sites listed in this section have a maximum geothermometer of greater than 90°C listed in the literature; however, all sites with geothermometers greater than 90°C were evaluated using the chemical concentrations also listed in the literature. A most likely reservoir temperature was determined for the sites in this section of less than 90°C.

To determine favorable volcanic sites, a table was used to screen sites according to volcanic rock age and composition.

Composition	Max. Age (10^3 Years)	
Basalt	Greater than	40
Andesite	Greater than	100
Rhyolite	Greater than	1,000

III. **Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature**
Exception: Excluding sites with a geothermometer of greater than or equal to 90°C.

IV. **Sites Failing Population/Distance Requirements**
Explanation: For direct use applications the "site" is the point of end use and the well or spring is the geothermal resource.

Screen: Sites with Population:	
1-100	Resource is on site
101-1,000	Resource is within 2 km
1,001-10,000	Resource is within 8 km
10,001-100,000	Resource is within 20 km
100,001+	Resource is within 40 km

I. Montana Sites in Legally-Designated Areas

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Lewis & Clark	Sun River Springs	22N 10W 26	30.4

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C or Volcanic Sites With Volcanics Older Than That of a Favorable Site - Montana

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
-- No Sites --			

IV. Montana Sites Failing Population/Distance Requirements

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Beaverhead	Anderson's Pasture Springs	13S	2W	18	26.0
	Apex Warm Spring	5S	9W	10	25.0
	Brown's Springs	8S	9W	30	23.8
	Lovells Hot Spring	8S	9W	28	19.4
	McNenomay Ranch Spring	9S	10W	29	19.0
	Staudenmeyer Springs	13S	2W	17	28.0
Broadwater	Bruce Well	4N	1E	4	18.0
	Hunsaker Spring	4N	2E	32	24.5
	Plunkets Lake Warm Springs	4N	1E	27	16.5
	Werner Warm Springs	5N	1E	22	18.0
Gallatin	Targhee Sulfur Warm Springs	13S	4E	27	18.0
Granite	Bearmouth Warm Springs1	11N	14W	11	20.2
	Bearmouth Warm Springs 2	11N	14W	12	15.0
	Nimrod Springs	11N	15W	14	20.5
Madison	New Biltmore Hot Springs	4S	7W	28	53.0
	Potosi Warm Springs 1	3S	2W	7	49.5
	Potosi Warm Springs 2 and 3	3S	2W	15	37.0
	Pullers Hot Springs	8S	5W	1	44.0
	Sloan Cow Camp Spring	12S	1E	19	29.5
	Trudau Warm Springs	7S	4W	7	22.7
	Vigilante Spring	9S	3W	22	23.5
	West Fork Swimming Hole	12S	1E	18	26.0
	Wolf Creek Hot Spring	10S	1E	9	68.0
Meagher	Ringling Well	7N	7E	25	48.0
Ravalli	Blue Joint Hot Springs 1	2S	23W	1	28.8
	Blue Joint Hot Springs 2	2S	22W	6	29.4
Sanders	Green Springs	20N	24W	33	18.9

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature - Montana

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Beaverhead	Uranium Test Well	2S 15W 14	15.5
Broadwater	Hunsaker Spring	4N 2E 18	15.0
	Toston Warm Springs	4N 3E 6	15.0
Ravalli	Florence Well	10N 20W 12	15.0

FINAL SITE LISTS - MONTANA

I. Electrical Generation Sites

An electrical generation site is a geothermal well or spring with a geothermometer of greater than or equal to 90°C, or an area displaying recent volcanic activity and high heat flow. These sites have been screened.

II. Direct Utilization Sites

A direct utilization site is a point of end use, such as a city or town. A geothermal well or spring is considered the resource. These sites have been screened.

I. Electrical Generation Sites - Montana

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Beaverhead	Jackson Spring	5S	15W	58.0	125.0
Deer Lodge	Gregson (Fairmont) Hot Springs	3N	10W	70.0	118.0
Jefferson	Boulder Hot Springs	5N	4W	76.0	136.0
Lewis & Clark	Broadwater Hot Spring	10N	4W	62.0	118.0
	Marysville Well	12N	8W	96.5	--
Madison	Ennis Hot Springs	5W	1W	83.2	129.0
	Norris Hot Springs	3S	1W	52.5	107.0
	Silver Star Hot Springs	2S	6W	71.5	131.0

II. Direct Utilization Sites - Montana

COUNTY	SITE	LOCATION (T,R,S)	POP.	MEASURED TEMP. (°C)
Beaverhead	Polaris	4S 12W 29	20	48.5
Broadwater	Townsend	7N 1E 23	1,371	23.6
Deer Lodge	Anaconda	3N 10W 11	9,771	24.0
	Warm Springs	5N 10W 24	500	77.0
Gallatin	Bozeman	2S 4E 14	18,670	54.6
Jefferson	Clancy	8N 3W 16	230	55.6
	Whitehall	2N 5W 28	1,035	57.0
Lake	Hot Springs	22N 23W 29	675	50.0
Meagher	White Sulphur Springs	9N 7E 18	1,200	46.0
Missoula	Lolo	11N 23W 7	10	44.0
Park	Emmigrant	6S 8E 1	15	42.0
	Gardiner	8S 8E 32	600	65.0
	Livingston	3S 9E 1	6,883	28.0
Powell	Avon	10N 8W 24	220	25.5
	Deer Lodge	7N 10W 29	4,306	26.0
	Garrison	10N 9W 19	150	25.0
Ravalli	Grantsdale	4N 19W 7	81	52.0
	Sula	1N 20W 12	44	49.0
Sanders	Camas	21N 24W 3	20	49.0
	Paradise	18N 25W 9	250	46.0

MASTER LIST OF GEOTHERMAL RESOURCE SITES - OREGON

The sites are organized by county.

A site is a well or spring which exhibits geothermal influence, or an area displaying recent volcanic activity and high heat flow.

MASTER LIST OF GEOTHERMAL RESOURCE SITES - OREGON

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Baker	Kropp Hot Spring	6S	39E	25	32.0
	Fisher Hot Springs	7S	38E	10	37.0
	Radium Hot Springs	7S	39E	28	57.0
	Well	8S	37E	29	57.0
	Flagstaff Point Hot Spring	9S	40E	1	21.0
	Sam O Spring	9S	40E	16	27.0
	Well	9S	40E	19	20.0
	Virtue Mine Warm Spring	9S	41E	21	--
	Nelson Spring	12S	43E	11	27.0
	Well	14S	43E	12	22.0
	Huntington City Well	14S	45E	18	24.0
Clackamas	NW Geothermal Old Maid Flat 7-A	2S	8E	15	121.0
	NW Geothermal Old Mail Flat 1	2S	8E	15	82.0
	USGS Clear Fork Well	2S	8E	17	32.0
	Mt. Hood Fumaroles	2S	9E	29	90.0
	Swim Warm Springs	3S	8½E	24	26.0
	NW Geothermal	3S	8½E	25	21.0
	Trillium Lake Well				
	USGS Pucci Chairlift 55-7	3S	9E	7	80.0
	Warm Water Well	6S	6E	34	21.0
	Grad Hole	6S	7E	30	55.0
	Austin Hot Springs	6S	7E	30	86.0
	Bagby Hot Springs	7S	5E	26	58.0
	EWEB Sisi Butte Grad Hole	8S	8E	6	29.0
Crook	Rhoden Well	14S	17E	33	22.0
	Powell Buttes System	15-16S	14-15E		20-57.0
	Martin Well	16S	15E	26	21.0
	Shumway Windmill Well	16S	15E	29	21.0
	Bowen Well	17S	15E	20	26.0
	Glover Well	17S	16E	32	20.0
	Camp Creek Well	19S	21E	5	23.0
	Gilchrist Valley HS	20S	22E	25/26	31.0
Deschutes	Crane Water Well	19S	14E	24	22.0
	DOGAMI Grad. Hole	19S	16E	16	26.0
	Decker Well	20S	16E	24	25.0
	Newberry Volcano	21-22S	12-13E		21-265.0
	Bearwallow Butte	18S	10E		**
	China Hat/East Butte	22S	14E	10-12	**
	Frederick Butte	12S	19E	32	**
	Melvin/3-Creek Buttes	18S	8E		**
	Quartz Mountain	22S	15E	26	**
	Shukash Basin	28S	9E	31	**
	South Sister	17S	18E		*
Douglas	Umpqua Hot Springs	26S	4E	20	47

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Gilliam	Wells	2-3N	21-22E		21-22.0
	Well	2S	21E	36	21.0
	Condon Area	4S	21E		20-25.0
	Arlington Well	3N	21E	21	22.0
Grant	Ritter Hot Springs	8S	30E	8	43.0
	Hot Sulphur Springs	10S	32E	35	49.0
	Mt. Vernon Hot Springs	13S	30E	9	49.0
	Limekiln Hot Spring	14S	33E	10	21.0
	Blue Mountain Hot Springs	14S	34E	13	58.0
	Joaquin Miller Hot Springs	15S	31E	11	40.0
	Brisbois Ranch Springs	17S	27E	24	22.0
	Weberg Hot Spring	18S	26E	18	46.0
Harney	Warm Springs	19S	26E	5	29.0
	Hot Spring	20S	34E	4	74.0
	Sitz Warm Spring	20S	34E	36	--
	Altnow Hot Spring	20S	36E	4	--
	Thomas Well Area	22S	32E	35	72.0
	Cow Creek Spring	22S	32½E	14	22.0
	Riverside Area	22S	36E	23	62.0
	Burns Area	23S	31E	9	71.0
	Well	24S	26E	24	21.0
	Ninemile Well	24S	32E	1	38.0
	HVDC Well	24S	32E	8	55.0
	Test Well	24S	32½E	9	57.0
	Lawen Well	24S	32½E	23	21.0
	Crane HS	24S	33E	34	78.0
	Dog Mountain Well	25S	30E	24	60.0
	Venatore HS	25S	36E	16	42.0
	S. Harney Lake Area	27S	29½E	36	67.0
	Howell Oil Well	26S	32E	5	41.0
	Thompson Well Area	26S	33E	13	24.0
	Voltage Well	27S	32E	14	22.0
	Basco Well	28S	29½E	19	23.0
	Frenchglen Area	32S	32E	12	32.0
	Mickey HS	33S	35E	13	87.0
	Alvord HS	34S	34E	32	78.0
	Fields Area	37S	32 3/4E	36	27.0
	Borax Lake HS	37S	33E	11	97.0
	Flagstaff Butte HS	39S	27E	16	53.0
	Hot Spring	38S	36E	19	35.0
	Deafenbough HS	39S	35E	16	57.0
	Diamond Craters	28S	32E	33	**
Hood River	Water Well	1N	9E	1	22.0
	Gradient Hole	1S	10E	1	20.0
	USGS McGee Creek	2S	8E	1	57.0
	Cascade Locks Area	2N	7E		20-25.0
	Hood River Area	3N	10E		20-25.0
	Parkdale Area	1S	10E		20-25.0

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Jackson	Jackson HS area	38S	1E	31	44.0
	Mt. McLoughlin Area	36S	4E	14	*
	Rustler Peak	34S	4E	16	**
Jefferson	Well	11S	13E	24	25.0
	Well	11S	15E	22	48.0
Klamath	Tulana Farms Well	35S	7E	19	21.0
	Lamm Lumber Co. Well	36S	7E	15	21.0
	Eagle Point Spring	36S	7E	23	34.0
	Viera/Mitchell Wells	36S	11E	14	22.0
	Sprague River Area	36S	11E	17	23.0
	Beatty Area	36S	12E	14	--
	Bly Area	36S	14E	25	21.0
	Klamath Falls Area	38-39S	8-9E		114.0
	Klamath Hills Area	40S	9E	27C	90.0
	Olene Gap Area	39S	10E	14	87.0
	Bonanza Area	39S	12E	19	89.0
	Lorella Area	40S	13E	10	61.0
	Langel Valley Area	41S	13E	12	23.0
	Warm Spring	41S	15E	3	33.0
	Cappy-Burn Butte	26S	6-7E	13	**
	Crater Lake Area	30-32S	7-7½E		*
Lake	Glass Buttes Mine Well	23S	23E	27	48.0
	Buckhorn Creek Springs	30S	17E	5	20.0
	Lost Cabin Spring	30S	17E	25	20.0
	Pardon Warm Spring	31S	16E	3	24.0
	D T O'Connor Well	31S	16E	22	26.0
	Currier Well	32S	16E	36	27.0
	Paisley Lake Area	33S	18E	23	111.0
	Abert Rim Area	34S	21E		27.0
	Antelope HS	35S	26E	32	40.0
	Bean-Antone Area	37S	20E	34	23.0
	Lakeview Area	39S	20E	4	96.0
	Moss Springs Area	38S	24E		29.0
	Lakeview Oil well	39S	19E	16	43.0
	Garrett Well	39S	19E	35	22.0
	West Side Area	40S	19E		27.0
	Rockford Ranch	41S	20E	1	77.0
	Crump Geyser Area	38S	24E	34	121.0
	Fisher HS Area	38S	25E	10	68.0
	Hallinan Spring Area	40S	24E	29	66.0
	Cougar Peak	38S	18E	6	**
	Devils Garden Area	24S	15E	17	**
	Four Craters Area	25S	17E	34	**
	Squaw Ridge Area	23S	16E	25-26	**
	Wart Peak Caldera	26S	12E	28	**

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Lane	Bigelow HS	15S	6E	22	61.0
	Belknap Springs	16S	6E	11	89.0
	Foley Springs	16S	6E	28	81.0
	Terwilliger HS	17S	5E	20	42.0
	Wall Creek WS	20S	4E	26	41.0
	Oakridge Area	21S	3E	17	30.0
	McCredie HS	21S	4E	36	73.0
	Kitson HS	22S	4E	6	43.0
Linn	EWEB Hole	12S	7E	9	31.0
	EWEB Hole	13S	7E	32	25.0
	Well	15S	6E	11	75.0
	Generic High Cascades***	13S	6E		**
Malheur	Well	15S	45E	7	23.0
	Jamieson Area	16S	43E	15	28.0
	Well	16S	44E	15	63.0
	Well	16S	46E	19	85.0
	Alkalai Gulch Area	17S	44E	11	51.0
	Gradient Hole	17S	44E	13	24.0
	Gradient Hole	17S	46E	16	28.0
	Neal HS Area	18S	43E	9	88.0
	Vale HS Area	18S	45E	20	115.0
	Ontario Area	18S	47E	4	25.0
	Beulah HS	19S	37E	2	60.0
	Harper WS	19S	42E	29	28.0
	Vines Hill Well	19S	43E	22	38.0
	Little Valley Area	19S	43E	30	70.0
	Sand Hollow Area	19S	44E		46.0
	Cow Hollow Area	19S	45E	28	38.0
	Oil Well	19S	47E	8	25.0
	Juntura Area	21S	38E	17	35.0
	Well	19S	47E	8	25.0
	Mitchell Butte Area	21S	45E	14	79.0
	Adrian Area	21S	46E	33	46.0
	Napton Area	22S	46E	12	41.0
	Lake Owyhee HS	23S	44E	10	--
	Luce HS	24S	37E	20	63.0
	Hot Spring	24S	44E	18	41.0
	Well	26S	46E	28	21.0
	Well	27S	38E	23	21.0
	Hot Spring	27S	43E	18	--
	Hot Spring	29S	41E	4	--
	Canters HS	30S	46E	2	49.0
	Scott Spring	32S	42E	21	20.0
	Tudors Springs	33S	39E	14	20.0
	3 Forks HS	35S	45E	3	35.0
	Wells	36S	41E	26	29.0
	Blue Mountain Well #1	37S	41E	34	44.0
	McDermitt Area	40S	42E	23	52.0

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Malheur (Continued)	Well	20S	46E	34	21.0
	Jackies Butte Field	34S	42E	7	**
	Jordan Craters Area	28S	43E	24	**
Marion	Breitenbush Area	9S	7E	20	118.0
	Mt. Jefferson Domes	10S	8E		*
Morrow	Well	4N	25E	10	20.0
	Spring	2N	25E	28	27.0
	Well	2N	26E	32	22.0
	Well	2N	27E	7	32.0
	Boardman Area	4N	25E		20-25.0
	Irrigon Area	5N	27E		20-25.0
	Ione Area	1S	24E		20-25.0
	Lexington Area	1S	25E		20-25.0
	Heppner Area	2S	26E		20-25.0
Multnomah	Corbett Warm Spring	1N	4E	27	23.0
	YMCA Camp Collins Well	1S	4E	10	21.0
Sherman	Grass Valley Area	2S	16E		20-25.0
	Moro Area	1S	17E		20-25.0
	Wasco Area	1N	17E		20-25.0
	Rufus Area	3N	17E		20-25.0
	Biggs Area	2N	16E		20-25.0
Umatilla	Campbell Well	6N	33E	23	29.0
	Kessler Well	6N	34E	30	24.0
	Unnamed Well	5N	35E	5	24.0
	Hermiston City Well	4N	28E	10	24.0
	Water Well	3N	30E	6	23.0
	Bingham Springs	3N	37E	18	34.0
	Lehman Springs	5S	33E	12	61.0
	Hidaway Springs	5S	33E	17	38.0
	Umatilla Area	5N	28E		20-25.0
	Milton-Freewater Area	5N	35E		20-25.0
	Stanfield Area	4N	29E		20-25.0
	Echo Area	3N	29E		20-25.0
	Pendleton Area	2N	32E		20-25.0
	Weston Area	4N	35E		20-25.0
	Athena Area	4N	35E		20-25.0
	Helix Area	4N	33E		20-25.0
	Pilot Rock Area	1S	32E		20-25.0
Union	Imbler Area	1S	38E	24	32.0
	La Grande Area	3S	38E	6	27.0
	Hunters Spring	3S	34E	35	31.0
	Cove Area	3S	40E	22	29.0
	Starkey WS	4S	36E	31	32.0
	Hot Lake Area	4S	39E	5	85.0
	Union Area	4S	39E	23	37.0

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Union (Continued)	Barstad Hot Well	4S	39E	33	82.0
	Warm Springs	5S	39E	23	38.0
	Cooper WS	5S	40E	12	23.0
	Bennett/Baker WS	5S	40E	16	27.0
	Warm Mineral Spring	6S	35E	12	28.0
	Medical HS	6S	41E	25	61.0
Wallowa	Cook Creek HS	5N	48E	30	36.0
Wasco	Sandoz Well	1N	12E	14	28.0
	Martin Well	1N	13E	32	22.0
	Water Well	2S	12E	3	27.0
	Kahneeta Hot Springs Area	8S	13E	20	52.0
	Maupin Area	4S	14E		20-25.0
	Tygh Valley Area	4S	13E		20-25.0
	Dufur Area	1S	13E		20-25.0
	The Dalles Area	1N	13E		20-25.0
	Mosier Area	2N	11E		20-25.0
	Rajneeshpuram Well	8S	18E	15	23.0
Wheeler	Spray City Well	8S	24E	36	33.0

* Denotes a large volcano with high heat flow and composed of recent volcanic rocks.

** Denotes recent volcanic activity in areas with high heat flow.

*** Generic High Cascades refers to a specific area that was analyzed by ODOGAMI for the assessment study. This area is typical of many other volcanic areas with a heat flow greater than 100 MW/m^2 (see Figure 3.6) and exhibiting north-south trending faults.

LIST OF SCREENED GEOTHERMAL RESOURCES SITES - OREGON

I. Sites in Legally-Designated Areas
Includes: National Parks, National Monuments, and Wilderness Areas

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites With Volcanics Older Than That of a Favorable Site
Explanation: The sites listed in this section have a maximum geothermometer of greater than 90°C listed in the literature; however, all sites with geothermometers greater than 90°C were evaluated using the chemical concentrations also listed in the literature. A most likely reservoir temperature was determined for the sites in this section of less than 90°C.

To determine favorable volcanic sites, a table was used to screen sites according to volcanic rock age and composition.

Composition	Max. Age (10^3 Years)	
Basalt	Greater than	40
Andesite	Greater than	100
Rhyolite	Greater than	1,000

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature
Exception: Excluding sites with a geothermometer of greater than or equal to 90°C.

IV. Sites Failing Population/Distance Requirements
Explanation: For direct use applications the "site" is the point of end use and the well or spring is the geothermal resource.

Screen: Sites with Population:	
1-100	Resource is on site
101-1,000	Resource is within 2 km
1,001-10,000	Resource is within 8 km
10,001-100,000	Resource is within 20 km
100,001+	Resource is within 40 km

I. Oregon Sites in Legally-Designated Areas

COUNTY	SITE	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Clackamas	Mt. Hood Fumaroles	2S	9E	29	90.0
	USGS Pucci Chairlift 55-7	3S	9E	7	80.0
Deschutes	South Sister	17S	18E		*
Harney	S. Harney Lake area	27S	29½E	36	67.0
	Howell Oil Well	26S	32E	5	41.0
	Frenchglen Area	32S	32E	12	32.0
Lake	Antelope HS	35S	26E	32	40.0
Malheur	Hot Spring	24S	44E	18	41.0
	Hot Spring	27S	43E	18	--
	Hot Spring	29S	41E	4	--
Marion	Mt. Jefferson Domes	10S	8E		*

* Denotes a large volcano with high heat flow and composed of recent volcanic rocks.

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C or Volcanic Sites With Volcanics Older Than That of a Favorable Site - Oregon

COUNTY	SITE	LOCATION (T,R,S)		MEASURED TEMP. (°C)
Baker	Radium HS	7S	39E	57
	Sam-O-Spring	9S	40E	27
Clackamas	Swim WS	3S	8½E	26
Crook	Powell Buttes	16S	14E	57
Grant	Joaquin Miller Resort	15S	31E	40
Harney	Harney Lake Area	27S	29½E	67
	Harney Valley Oil Test Well	24S	32E	46
	Hines Area	23S	30E	25
	Island Ranch Well	25S	32E	41
	Riverside Area	22S	36E	62
	Venatore Area	25S	36E	41
Kitson HS	22S	4E	44	100
	Terwilliger HS	17S	5E	42
Multnomah	Corbett WS	1N	4E	23
Umatilla	Bingham WS	3N	37E	34
Union	Wagner Well	1S	38E	29
Wallowa	Cook Creek WS	5N	48E	36
Wasco	Martin Well	1N	13E	22
	Sandoz Well	1N	12E	28

** Denotes recent volcanic activity in areas with high heat flow.

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature - Oregon

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Gilliam	Wells	2-3N 21-22E	21-22.0
Hood River	Gradient Hole	1S 10E 1	20.0
Morrow	Well	4N 25E 10	20.0

IV. Oregon Sites Failing Population/Distance Requirements

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Baker	Fisher Hot Springs	7S 38E 10	37.0
	Well	8S 37E 29	57.0
	Flagstaff Point Hot Spring	9S 40E 1	21.0
	Virtue Mine Warm Spring	9S 41E 21	--
	Nelson Spring	12S 43E 11	27.0
	Well	14S 43E 12	22.0
Clackamas	NW Geothermal Old Maid Flat 7-A	2S 8E 15	121.0
	NW Geothermal Old Maid Flat 1	2S 8E 15	82.0
	USGS Clear Fork Well	2S 8E 17	32.0
	NW Geothermal Trillium Lake Well	3S 8½E 25	21.0
	USGS Pucci Chairlift 55-7	3S 9E 7	80.0
	Warm Water Well	6S 6E 34	21.0
	Grad Hole	6S 7E 30	55.0
	Bagby Hot Springs	7S 5E 26	58.0
	EWEB Sisi Butte Grad Hole	8S 8E 6	29.0
Crook	Rhoden Well	14S 17E 33	22.0
	Martin Well	16S 15E 26	21.0
	Shumway Windmill	16S 15E 29	21.0
	Bowen Well	17S 15E 20	26.0
	Glover Well	17S 16E 32	20.0
	Camp Creek Well	19S 21E 5	23.0
	Gilchrist Valley HS	20S 22E 25-26	31.0
Deschutes	Crane Water Well	19S 14E 24	22.0
	DOGAMI Grad Hole	19S 16E 16	26.0
	Decker Well	20S 16E 24	25.0
Gilliam	Wells	2-3N 21-22E	21-22.0
	Well	2S 21E 36	21.0
Grant	Hot Sulphur Springs	10S 32E 35	49.0
	Mt. Vernon Hot Springs	13S 30E 9	49.0
	Limekiln Hot Spring	14S 33E 10	21.0
	Joaquin Miller Hot Springs	15S 31E 11	40.0
	Brisbois Ranch Springs	17S 27E 24	22.0
Harney	Warm Springs	19S 26E 5	29.0
	Hot Spring	20S 34E 4	74.0
	Sitz Warm Spring	20S 34E 36	--
	Altnow Hot Spring	20S 36E 4	--
	Thomas Well Area	22S 32E 35	72.0
	Cow Creek Spring	22S 32½E 14	22.0
	Well	24S 26E 24	21.0
	Ninemile Well	24S 32E 1	38.0
	HVDC Well	24S 32E 8	55.0
	Test Well	24S 32½E 9	57

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Harney (Continued)	Lawen Well	24S 32½E 23	21.0
	Dog Mountain Well	25S 30E 24	60.0
	S. Harney Lake Area	27S 29½E 36	67.0
	Howell Oil Well	26S 32E 5	41.0
	Voltage Well	27S 32E 14	22.0
	Basco Well	28S 29½E 19	23.0
	Frenchglen Area	32S 32E 12	32.0
	Fields Area	37S 32 3/4E 6	27.0
	Hot Spring	38S 36E 19	35.0
	Deafenbough HS	39S 35E 16	57.0
Hood River	Water Well	1N 9E 1	22.0
	Gradient Hole	1S 10E 1	20.0
	USGS McGee Creek	2S 8E 1	57.0
Jefferson	Well	11S 13E 24	25.0
	Well	11S 15E 22	48.0
Klamath	Tulana Farms Well	35S 7E 19	21.0
	Lamm Lumber Co. Well	36S 7E 15	21.0
	Eagle Point Spring	36S 7E 23	34.0
	Viera/Mitchell Wells	36S 22E 14	22.0
	Sprague River Area	36S 11E 17	23.0
	Beatty Area	36S 12E 14	--
	Bly Area	36S 14E 25	21.0
	Bonanza Area	39S 12E 19	93.0
	Lorella Area	40S 13E 10	61.0
	Langel Valley Area	41S 13E 12	23.0
	Warm Spring	41S 15E 3	33.0
Lake	Buckhorn Creek Springs	30S 17E 5	20.0
	Lost Cabin Spring	30S 17E 25	20.0
	Pardon Warm Spring	31S 16E 3	24.0
	D T O'Connor Well	31S 16E 22	26.0
	Currier Well	32S 16E 36	27.0
	Abert Rim Area	34S 21E	27.0
	Antelope HS	35S 26E 32	40.0
	Bean-Antone Area	37S 20E 34	23.0
	Moss Springs Area	38S 24E	29.0
	Lakeview Oil Well	39S 19E 16	43.0
	Garrett Well	39 19E 35	22.0
	West Side Area	40S 19E	27.0
	Rockford Ranch	41S 20E 1	77.0
Linn	EWEB Hole	12S 7E 9	31.0
	EWEB Hold	13S 7E 32	25.0
	Well	15S 6E 11	75.0
Malheur	Well	15S 45E 7	23.0
	Jamieson Area	16S 43E 15	28.0

COUNTY	SITE	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Malheur (Continued)	Well	16S 44E 15	63.0
	Well	16S 46E 19	85.0
	Alkalai Gulch Area	17S 44E 11	51.0
	Gradient Hole	17S 46E 13	24.0
	Gradient Hole	17S 46E 16	28.0
	Harper WS	19S 42E 29	28.0
	Vines Hill Well	19S 43E 22	38.0
	Sand Hollow Area	19S 44E	46.0
	Cow Hollow area	19S 45E 28	38.0
	Oil Well	19S 47E 8	25.0
	Juntura Area	21S 38E 17	35.0
	Well	19S 47E 8	25.0
	Napton Area	22S 46E 12	41.0
	Lake Owyhee HS	23S 44E 10	--
	Hot Spring	24S 44E 18	41.0
	Well	26S 46E 28	21.0
	Well	27S 38E 23	21.0
	Hot Spring	27S 43E 4	--
	Scott Spring	32S 42E 21	20.0
	Tudors Springs	33S 39E 14	20.0
	3 Forks HS	35S 45E 3	35.0
	Wells	36S 41E 26	29.0
	Blue Mountain #1	37S 41E 34	44.0
	Well	20S 46E 34	21.0
Morrow	Well	4N 25E 10	20.0
	Spring	2N 25E 28	27.0
	Well	2N 26E 32	22.0
	Well	2N 27E 7	32.0
Umatilla	Campbell Well	6N 33E 23	29.0
	Kessler Well	6N 34E 30	24.0
	Unnamed Well	5N 35E 5	24.0
	Water Well	3N 30E 6	23.0
	Lehman Springs	5S 33E 12	61.0
	Hidaway Springs	5S 33E 17	38.0
Union	Hunters Spring	3S 34E 35	31.0
	Starkey WS	4S 36E 31	32.0
	Barstad Hot Well	4S 39E 33	82.0
	Warm Springs	5S 39E 23	38.0
	Cooper WS	5S 40E 12	23.0
	Bennett/Baker WS	5S 40E 16	27.0
	Warm Mineral Spring	6S 35E 12	28.0
Wasco	Water Well	2S 12E 3	27.0

I. Electrical Generation Sites

An electrical generation site is a well or spring with a geothermometer of greater than or equal to 90°C, or an area displaying recent volcanic activity and high heat flow. These sites have been screened.

II. direct utilization sites

A direct utilization site is a point of end use, such as a city or town. A geothermal well or spring is considered the resource. These sites have been screened.

I. Electrical Generation Sites - Oregon

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Baker	Krop HS	6S	39E	32	110
Clackamas	Austin HS	6S	7E	86	126
	Mt. Hood Flanks	2S	9E	90	150
Dechutes	Newberry Volcano	21S	13E	265	280
	Bearwallow Butte	18S	10E	**	**
	China Hat/East Butte	22S	14E	**	**
	Frederick Butte	12S	19E	**	**
	Melvin/3-Creek Buttes	18S	8E	**	**
	Quartz Mountain	22S	15E	**	**
	Shukash Basin	28S	9E	**	**
Douglas	Umpqua HS	26S	4E	47	136
Grant	Blue Mountain HS	14S	34E	58	126
	Weberg HS	18S	26E	46	126
Harney	Alvord HS	34S	34E	78	231
	Borax Lake HS	37S	33E	97	231
	Crane HS	24S	33E	78	127
	Mickey HS	33S	35E	87	227
	O.J. Thomas Well	22S	32E	72	131
	Flagstaff Butte HS	39S	37E	53	180
	Diamond Craters	28S	32E	**	**
Jackson	Mt. McLoughlin Area	36S	4E	*	*
	Rustler Peak	34S	4E	**	**
Klamath	Klamath Hills Area	40S	9E	93	138
	Klamath Falls Area	38S	9E	114	131
	Olene Gap HS	39S	10E	74	136
	Cappy-Burn Butte	26S	6-7E	**	**
	Crater Lake Area	30-32S	7-7½E	*	*
Lake	Barry Ranch HS	39S	20E	85	157
	Crump HS	38S	24E	121	185
	Fischer HS	38S	25E	68	123
	Glass Buttes Mine Well	23S	23E	48	--
	Hallinan Springs	40S	24E	66	136
	Lakeview Area	39S	20E	96	158
	Summer Lake HS	33S	17E	51	134
	Cougar Peak	38S	18E	**	**
	Devils Garden Area	24S	15E	**	**
	Four Craters Area	25S	17E	**	**
	Squaw Ridge Area	23S	16E	**	**
	Wart Peak Caldera	26S	12E	**	**

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Lane	Belknap HS	16S	6E	89	148
	Bigelow HS	15S	6E	61	117
	Foley HS	16S	6E	81	111
	McCredie HS	21S	4E	73	96
	Wall Creek HS	20S	4E	41	113
Linn	Generic High Cascades***	13S	6E	--	--
Malheur	Beulah HS	19S	37E	60	169
	Little Valley Area	19S	43E	70	145
	Luce HS	24S	37E	63	143
	McDermitt Area	40S	42E	52	120
	Mitchell Butte HS	21S	45E	62	134
	Neal HS	18S	43E	88	210
	Vale HS	18S	45E	115	161
	Jackies Butte Field	34S	42E	**	**
	Jordan Craters Area	28S	43E	**	**
Marion	Breitenbush HS	9S	7E	118	149
Union	Medical HS	6S	41E	61	125
Wasco	Kahneeta HS	8S	13E	52	113

* Denotes a large volcano with high heat flow and composed of recent volcanic rocks.

** Denotes recent volcanic activity in areas with high heat flow.

*** Generic High Cascades refers to a specific area that was analyzed by ODOGAMI for the assessment study. This area is typical of many other volcanic areas with a heat flow greater than 100 MW/M^2 (see Figure 3.6) and exhibiting north-south trending faults.

II. Direct Utilization Sites - Oregon

COUNTY	SITE	LOCATION (T,R,S)	POP.	MEASURED TEMP. (°C)
Baker	North Powder	6S 39E 25	440	43
	Haines	7S 39E 28	355	58
	Baker	9S 40E 16	9,690	27
	Huntington Area	14S 45E 18	550	24
Clackamas	Government Camp	3S 8½E 24	550	26
Gilliam	Arlington	3N 21E 21	455	22
Grant	Ritter Hot Springs	8S 30E 8	40	41
Harney	Burns Area	23S 31E 9	4,350	71
Hood River	Parkdale	1S 10E 6	250	24
Jackson	Ashland	39S 1E 9	14,943	44
Klamath	Klamath Falls Area	38-39S 8-9E	17,100	114
Lake	Paisley Lake Area	33S 18E 23C	345	111
	Lakeview Area	39S 20E 4	2,810	96
Lane	Oakridge Area	21S 3E 17	3,560	29
Malheur	Vale HS Area	18S 45E 20	1,560	111
	Ontario Area	18S 47E 4	9,125	25
	Adrian Area	21S 46E 33	175	46
	Jordan Valley	30S 46E 2	460	50
Morrow	Boardman Area	4N 25E	1,190	26
	Heppner Area	2S 26E	1,385	20-25
	Irrigon Area	5N 27E	870	20-25
	Lexington Area	1S 25E	290	20-25
Multnomah	Troutdale	1N 4E 27	6,545	23
Umatilla	Athena area	4N 35E 19	955	21
	Echo Area	3N 29E 16	610	22
	Hermiston	4N 28E 10	9,630	24
	Milton-Freewater Area	5N 35E 1	5,415	24
	Pendleton Area	2N 32E	14,550	20
	Pilot Rock Area	1S 32E 16	1,640	20
	Stanfield Area	4N 29E 32	1,620	22
	Umatilla Area	5N 28E 17	2,990	22
	Weston Area	4N 35E 22	705	21
Union	Imbler Area	1S 38E 24	290	29
	La Grande Area	3S 38E 6	11,920	26
	Cove Area	3S 40E 22	475	30
	Union Area	4S 39E 23	2,065	85

COUNTY	SITE	LOCATION (T,R,S)	POP.	MEASURED TEMP. (°C)
Wasco	Kahneeta Hot Springs Area	8S 13E 20	100	83
	Rajneeshpurem	8S 18E 15	1,500	20
	The Dalles	1N 13E	11,260	23
Wheeler	Spray	8S 24E 36	125	33

MASTER LIST OF GEOTHERMAL RESOURCE SITES - WASHINGTON

The sites are organized by county.

A site is a well or spring which exhibits geothermal influence, or an area displaying recent volcanic activity and high heat flow.

MASTER LIST OF GEOTHERMAL
RESOURCE SITES - WASHINGTON

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Adams	Well	15N	28E	4	AA	26.4
	CMST P&P	15N	28E	8	BC	20.0
	USBR	15N	28E	15	BB	24.2
	DH-4	15N	28E	30	CA	53.5
	ECBID	15N	28E	35	CD	24.4
	Othello-2	15N	29E	3	BA	22.8
	Othello-4	15N	29E	3	DA	20.8
	Othello-5	15N	29E	3	CD	29.0
	Othello-6	15N	29E	4	AA	25.2
	Othello-1	15N	29E	4	AA	20.0
	McKay	15N	31E	5	CA	26.4
	Lyle Bros-3	15N	31E	11	BC	20.5
	Johnson	15N	31E	19	AA	25.5
	Damon	15N	32E	4	AB	21.8
	Stelger	15N	32E	16	BD	20.0
	Hart	15N	32E	35	BC	27.6
	Tompkins	15N	33E	2	AA	25.0
	Watson	15N	34E	27	DD	20.9
	Blauert	15N	36E	34	BD	25.4
	Othello-3	16N	29E	34	DD	24.8
	Kliphardt	16N	30E	24	BB	25.9
	Kliphardt	16N	30E	26	AA	26.2
	Andrews-2	16N	30E	27	DA	25.2
	DNR-Damon	16N	30E	36	DB	20.3
	Mike Damon	16N	30E	36	DB	25.8
	Lyle	16N	31E	15	AB	24.1
	Lyle (south)	16N	31E	15	DC	26.9
	Wholman	16N	31E	15	BB	26.2
	Phillips-12	16N	32E	11	BB	27.7
	Phillips	16N	32E	14	BA	20.7
	Phillips-11	16N	32E	14	BB	20.0
	Phillips-17	16N	32E	15	BB	33.4
	Phillips	16N	32E	20	CC	29.2
	Phillips-10	16N	32E	21	BC	27.4
	Phillips	16N	32E	23	BB	21.6
	Phillips-2	16N	32E	25	BB	28.7
	Phillips-16	16N	32E	25	CC	31.0
	Phillips-C-34	16N	32E	34	BC	43.4
	Phillips-9	16N	32E	35	BB	24.0
	Baumann	16N	35E	31	DC	22.4
	Phillips C-12	17N	31E	12	BB	27.8
	DNR	17N	32E	14	CB	23.2
	City of Lind	17N	33E	12	CD	21.0
	Benge/Connell	17N	37E	27	BB	21.9
	Hutterites	18N	31E	18	BA	21.8
	Phillips C-33	18N	31E	33	BB	30.0
	Kagele	19N	31E	24	AC	20.1
	S&K Farms	19N	32E	24	DB	20.6

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Adams (Continued)	J&M Farms	19N	32E	24	CC	31.5
	Hoefel	19N	33E	8	DC	20.3
	Hoefel	19N	33E	8	DC	41.0
	Kagele	19N	34E	20	AB	22.5
	Gering	19N	36E	9	DB	20.4
	Heinemann-2	19N	36E	34	CC	20.7
	Well	19N	38E	13	BD	21.1
	Weber	20N	34E	2	DC	20.9
	Hardung	20N	35E	17	BB	20.9
	Ahern	20N	35E	24	BB	20.5
Asotin	WWP-2	10N	46E	3	DC	23.0
	WWP-5	11N	46E	30	DC	23.3
	WWP-C7-WW	11N	46E	32	BC	26.2
Benton	Sperry	04N	24E	3	AB	20.6
	Powers	05N	26E	5	BB	26.3
	Engineers	05N	28E	6	DD	21.5
	Columbia River	06N	24E	22	AB	22.5
	Craig	06N	26E	15	CB	24.2
	Blair	06N	30E	12	DC	21.1
	Irrigro	06N	30E	19	CC	20.5
	Horrigan Farms	07N	24E	8	BB	24.1
	DOE Patterson	07N	25E	36	CC	22.5
	DOE Patterson	07N	25E	36	CC	30.3
	DNR-Baker	07N	25E	36	CD	21.8
	DOE	07N	25E	36	CC	22.7
	Moon	07N	26E	5	AB	22.1
	DOE H Heaven	07N	27E	36	AA	26.3
	Prosser-5	08N	24E	1	DA	25.2
	DNR-Gould	08N	25E	36	AB	25.9
	Mott	08N	29E	22	AA	23.0
	Prosser Exp.	09N	25E	6	AB	27.8
	Chisten	09N	26E	27	DB	21.5
	DNR-Benton-40	09N	27E	16	BB	23.3
	DNR-Kid-3	09N	27E	23	CA	29.1
	DNR79-07	09N	27E	25	CB	21.6
	Bauder	09N	28E	34	AD	21.1
	DNR-Anderson	10N	24E	36	BD	29.8
	Nakamura	10N	25E	25	BC	20.6
	J&R Orchard	10N	25E	33	CC	21.8
	Hanford S6E4C	10N	27E	28	AA	20.9
	DH-3	10N	28E	14	AC	47.8
	Hanford S-30	10N	28E	14	AB	39.7
	VO-SOC1	11N	26E	20	CC	40.1
	U.S. Government	11N	26E	34	DD	24.0
	Hanford 2-E14	11N	28E	23	BB	26.2
	Tramel	12N	24E	5	AA	20.4
	Tramel	12N	24E	5	AA	23.0
	Roberts Bros.	12N	24E	20	CC	26.0

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Benton (Continued)	U.S. Government	12N	26E	4	CC	21.4
	U.S. Government	12N	26E	7	AB	20.7
	U.S. Government	12N	26E	7	DC	20.4
	U.S. Government	12N	26E	8	CD	21.2
	U.S. Government	12N	26E	12	AD	21.0
	U.S. Government	12N	26E	14	BB	21.1
	U.S. Government	12N	26E	15	BA	21.7
	U.S. Government	12N	26E	18	BC	20.5
	U.S. Government	12N	26E	18	AC	20.8
	U.S. Government	12N	27E	16	CB	20.5
	U.S. Government	13N	24E	25	BC	24.2
	Meeker	13N	24E	26	AC	20.0
	U.S. Government	13N	24E	36	BB	24.0
	U.S. Government	13N	25E	1	CC	23.0
	Well	13N	25E	11	AD	39.1
	McGee	13N	25E	30	AC	26.8
	DDH-1	13N	26E	35	AA	21.9
	ARH DC-1	13N	26E	35	DB	75.0
	Hanford DDH-1	13N	26E	35	AA	24.8
	ARH DC-1	13N	26E	35	AA	70.0
	Hanford DC-6	13N	27E	26	AC	60.2
	Well	14N	26E	14	CB	32.5
	Well	14N	26E	28	AC	20.7
	Hanford	14N	26E	28	DA	25.0
	Hanford	14N	26E	28	CD	25.5
	Hanford	14N	26E	29	DD	25.4
	Hanford	14N	26E	33	AC	27.0
Chelan	Norco-1	22N	20E	26	CB	35.7
	Medicine Spring	26N	18E	13	D	8.7
	Little Wenatchee Soda Spring	27N	15E	10	B	7.0
	Little Wenatchee Ford Soda Spring	28N	13E	14		9.0
Clallam	Olympic Hot Springs	29N	08W	28	B	48.0
	Sol Duc Hot Springs	29N	09W	32	B	50.0
	Piedmont Sulfur Spring	30N	09W	11		C
Clark	City of Vancouver Spring	02N	02E	33	C	10.0
Columbia	Ferrell	12N	38E	1	BC	22.0
	Well	13N	38E	26	BC	20.0
Cowlitz	Pigeon Springs	07N	01E	36	BA	C
	Green River Soda Springs	10N	04E	2	A	13-25
Douglas	Welch	20N	22E	12	AB	22.0
	Pixlee	23N	26E	20	BB	29.3
Franklin	Pasco	09N	30E	18	AD	21.0
	Nakamura	09N	31E	7	BC	24.6

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Franklin (Continued)	Nakamura	11N	31E	21	AD	24.2
	Well	12N	28E	8	AB	23.4
	U.S.B.R.	12N	29E	28	BD	20.0
	U.S.B.R.	13N	28E	13	CC	27.6
	Bailie	13N	29E	13	DB	22.6
	Cockrane	13N	34E	30	CB	32.2
	U.S. Government	14N	29E	9	AA	22.3
	Othello A.F.B.	14N	29E	9	AA	22.2
	Rathburn	14N	31E	8	CB	46.8
	Rathburn #3	14N	31E	9	DA	21.2
	Connell-4	14N	31E	36	DA	25.0
	Hart	14N	32E	2	CD	27.2
	Hart	14N	32E	13	BC	25.6
	Connell-6	14N	32E	31	BB	29.4
	Heider	14N	33E	21	CC	27.3
	Gillis	14N	36E	19	CC	23.0
Garfield	Pomeroy	12N	42E	31	CA	23.0
Grant	U.S. Army	14N	25E	1	BB	27.5
	Hanford 93-93	14N	25E	1	BB	25.6
	U.S. Government	14N	25E	21	AB	22.0
	U.S. Army	14N	27E	24	BA	30.0
	DH-5	15N	24E	25	CD	74.0
	Hanford DH-5	15N	24E	25	CD	72.7
	AEC	15N	27E	34	CA	21.5
	U.S. Government	16N	24E	1	AC	23.5
	U.S.A.F.	16N	24E	1	AC	24.5
	METRO	17N	25E	1	BD	25.3
	U.S.B.R.	17N	27E	31	BB	20.8
	Well	17N	30E	1	AC	23.0
	U.S. Army	17N	30E	33	DB	22.2
	U.S. Army	17N	30E	33	DB	23.5
	Washington	18N	25E	15	BC	25.6
	DOE-George	18N	25E	15	BC	22.4
	DOE-George	18N	25E	15	BC	29.3
	METRO M.-11A	18N	25E	23	DA	21.2
	Farm Man	18N	25E	27	CC	21.2
	Bradshaw	18N	25E	28	AB	22.4
	METRO M.-20	18N	26E	31	DB	22.5
	Shinn	18N	26E	35	C	23.2
	Am.Pot.Co.	18N	29E	6	DC	21.5
	Lauzier	19N	27E	31	BB	25.0
	Moses Lake 3	19N	28E	15	DC	22.2
	Moses Lake-7	19N	28E	23	BB	23.7
	Moses Lake	19N	28E	23	BA	22.0
	Moses Lake-10	19N	28E	27	DD	21.4
	Moses Lake-4	19N	28E	28	DB	22.6
	Fode-1	19N	29E	3	BD	25.4
	Shinn-2	19N	29E	4	AD	25.0

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Grant (Continued)	Abrams	19N	29E	9	DA	20.5
	Jett-Aero-2	19N	29E	14	DA	21.5
	Carnation	19N	29E	16	CC	28.8
	Potato-2	19N	30E	13	BD	20.2
	Schimidt	19N	30E	17	CB	21.8
	Abram-1	19N	30E	20	BB	25.8
	Quincy-1	20N	24E	7	DD	21.0
	Cole	20N	29E	7	AD	24.0
	Reinke	20N	29E	25	BA	25.0
	Powers	20N	29E	35	AA	25.0
	Claassen	20N	30E	21	BD	26.4
	Claassen	20N	30E	21	AC	22.0
	Claassen	20N	30E	21	AC	28.0
	Franz-2	20N	30E	23	AA	21.5
	Franz	20N	30E	23	BC	34.8
	Stuckey	20N	30E	28	DD	20.4
	Jantz	20N	30E	28	DD	28.5
	Neibauer	20N	30E	32	DB	21.2
	Ephrata	21N	26E	8	CB	30.0
	Ephrata-5	21N	26E	8	CC	28.0
	Ephrata-10	21N	26E	15	AD	21.3
	Ephrata	21N	26E	21	BC	25.5
	Well	21N	30E	10	CB	30.0
	Schell	21N	30E	26	AC	20.7
	Soap Lake	22N	27E	19	CC	27.0
	King	22N	30E	26	AC	25.0
	Schaffer	23N	28E	27	BC	22.8
	Well	25N	28E	24	AC	29.2
	Dormaier	25N	28E	25	AB	23.0
Grays Harbor	Newskah Mineral Springs	16N	9W	9		19.0
King	Lester Hot Springs	20N	10E	21		49.0
	Diamond Mineral Springs	21N	6E	21	C	11.0
	Flaming Geyser Springs	21N	6E	27	D	13.0
	Skykomish Soda Springs	26N	11E	27	B	C
	Money Creek Soda Springs	26N	11E	30	C	12.0
	Goldmeyer Hot Springs	23N	11E	14	B	53.0
	Scenic Hot Springs	26N	13E	32	A	50.0
Kittitas	Burbank	15N	19E	22	CA	22.8
	USGS Burbank	15N	19E	22	CA	23.4
	Larson Fruit	15N	19E	22	CD	31.5
	Badger	16N	19E	12	DB	20.0
	Bollinger	16N	19E	12	DB	20.0
	USGS-Umtanum	16N	19E	28	BA	26.8
	USGS Umtanum	16N	19E	28	BA	27.9
	Ellensburg RA	18N	18E	35	BC	20.8

COUNTY	SITE***	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Kittitas (Continued)	Central Washington College	18N	18E 36	AB	28.4
	Clerf	18N	20E 27	AA	19.3
	Medicine Creek Mineral Spring	21N	17E 22	DC	9.0
Klickitat	Leonardo Springs	02N	13E 21	B	14.0
	Gas-Ice Corp.	04N	13E 24	AD	27.2
	Klickitat Mineral Springs	04N	13E 24		15-29
	DNR81-Klick	04N	13E 24	BC	20.1
	Gas-Ice Corp.	04N	14E 19	BA	22.8
	Blockhouse Mineral Springs	04N	15E 9	C	12.0
	Barrett	04N	16E 11	BB	20.9
	Goldendale-1	04N	16E 16	AC	19.9
	Dingmon	04N	16E 28	AA	19.5
	Klickitat Soda Springs	04N	15E 9	C	12.0
	Case	05N	15E 25	DB	19.7
	Berk Bros.	05N	20E 27	AB	22.8
	Berk	05N	20E 27	AB	23.1
	DOE	05N	21E 16	CA	27.3
	Matsen	05N	22E 27	AA	28.2
	Powers	05N	23E 29	BB	26.2
	McBride	05N	23E 29	BB	25.5
	Fish Hatchery Warm Spring	05N	13E 25	DA	24.0
	Smith	06N	23E 11	CD	22.0
	Smith	06N	23E 11	DC	21.0
	Andrews	06N	23E 15	AD	25.2
	Andrews	06N	23E 22	DA	23.0
	DNR-Mercer N	06N	23E 36	BD	20.8
Lewis	SU-8	12N	01W 7	AA	25.2
	SU-14	12N	01W 8	CC	25.6
	SU-37	12N	01W 8	CC	24.7
	SU-11	12N	01W 8	DA	21.3
	SU-12	12N	01W 8	DA	25.7
	Longview-10	12N	01W 17		30.0
	SU-4	12N	01W 9	CC	28.8
	SU-902	12N	01W 17	AD	31.2
	Vance Mineral Spring	12N	07E 22	CB	C
	Alpha Mineral Spring	13N	02E 5		C
	Packwood Hot Spring	13N	09E 32		38.0
	Clear Fork Dacite	13N	9-10E		**
	Ohanapecosh Hot Springs	14N	10E 4	B	50.0
	Summit Creek Soda Springs	14N	11E 18	AC	12.0
Lincoln	Basalt Explr.	21N	31E 10	CB	65.8
	Basalt Explr.	21N	31E 10	CB	64.0
	Schell	21N	31E 10	CB	30.4
	DOE Basalt Ex	21N	31E 10	CB	28.9
	Bates	21N	31E 22	BC	19.8
	Sahible	21N	31E 25	AB	28.3
	Kissler	21N	31E 30	DD	22.8

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Lincoln (Continued)	Kissler	21N	31E	32	BB	21.1
	Schafer	21N	32E	23	BD	22.0
	Schafer	21N	32E	23	BD	24.1
	Hardung	21N	34E	33	BA	24.9
	Iverson	21N	35E	7	AC	20.1
	Weishaar	23N	32E	4	DA	28.7
	Weishaar	23N	32E	17	AC	21.2
	Zagelow	23N	32E	10	DA	21.6
	Zagelow	23N	33E	14	BC	19.2
	USGS Almira	24N	31E	16	BC	20.0
	USGS Almira	24N	31E	16	BC	20.1
	DOE	24N	31E	16	BC	21.8
	Schmierer	24N	33E	23	CD	25.9
	Nealey	24N	34E	30	CD	21.0
	USGS Davenport	24N	36E	16	AA	21.3
	DOE	24N	36E	16	AA	21.9
	Davenport-5	25N	37E	21	CA	24.0
	Reardan City	25N	39E	15	BB	20.0
	GEIB	26N	32E	10	AD	19.2
	Rexcon SF-15	27N	37E	22	CD	19.5
	Taylor	27N	37E	26	AA	23.8
Okanogan	Poison Lake	39N	27E	5	D	40-50
	Hot Lake	40N	27E	18	A	40-50
Pierce	St. Andrews Soda Spring	15N	07E	1		C
	Longmire Mineral Springs	15N	08E	29	D	25.0
	Mt. Rainier	15-16N	8-9E			*
	Mt. Rainier Fumaroles	16N	08E	23		52-72
Skamania	NB-2	02N	07E	16	DC	35.5
	NB-3	02N	07E	16	BD	25.4
	Bonneville Hot Springs	02N	07E	16	C	36.0
	Rock Creek Hot Springs	03N	07E	27	A	34.0
	DNR81-Carson	03N	08E	21	BD	27.8
	Shipherds Hot Springs	03N	08E	21	D	42.0
	St. Martin Hot Springs	03N	08E	21	D	53.0
	Collins Hot Springs	03N	09E	31	C	40-50
	Little Soda Spring	04N	07E	5	D	8.0
	Red Mountain-Big Lava Bed	4-5N	8-9E			**
	Puny Creek Basalt	05N	06E			**
	Government Mineral Springs	05N	07E	31		7.0
	Mann Butte	05N	09E			**
	Mt. St. Helens	8-9N	05E			*
	Mt. Adams	8-9N	10E			*
	Orr Creek Warm Springs	10N	10E	19	A	22.0
Snohomish	Garland Mineral Springs	28N	11E	25	B	29.0
	Kennedy Hot Springs	30N	12E	1	A	38.0
	Glacier Peak	30-31N	13E			*

COUNTY	SITE***	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Snohomish (Continued)	Gamma Hot Springs	31N 13E 24 D	60.0
	Suiattle R. Mineral Seep	31N 15E 18 A	10.0
	Sulphur Creek Hot Springs	32N 12½E 24 B	37.0
Spokane	Cheney City	23N 41E 14 DC	29.1
	Cheney City-5	23N 41E 14 DC	31.9
Walla Walla	Warm Spring Canyon Warm Spring	06N 32E 2 D	22.0
	Fulgham	06N 33E 1 DB	31.8
	Miller	06N 34E 2 AB	25.1
	Chvatel	06N 34E 6 AB	34.4
	Gilbert-Merry	06N 34E 7 CD	40.7
	Burlingame	06N 35E 3 CC	20.0
	Jaussand	06N 35E 10 CD	25.0
	McAuslan	06N 35E 12 AD	21.0
	Estes	06N 35E 12 CC	22.0
	Dept. of Ecology	06N 35E 18 AA	20.3
	Dept. of Ecology	06N 35E 18 AA	21.3
	Dept. of Ecology	06N 35E 18 AA	36.1
	College Place	06N 35E 18 AA	26.1
	Richardson	06N 36E 5 CB	21.0
	Baker	06N 36E 5 DD	27.0
	Courtney	06N 36E 6 CB	22.0
	Ruzicka	06N 36E 7 BB	22.0
	Baker	06N 36E 9 CA	22.0
	Baker	06N 36E 9 CD	23.0
	Byerly	07N 32E 36 DC	24.0
	Taggart	07N 33E 24 DC	23.2
	McDole	07N 33E 31 DB	27.7
	Baker	07N 34E 25 CC	20.0
	B.P.A.	07N 35E 23 CB	20.0
	Clock/B.P.A.	07N 35E 24 CB	20.0
	Arbini	07N 35E 25 BD	20.0
	Columbo	07N 35E 25 CD	20.0
	Walla Walla C	07N 35E 33 AD	24.0
	DNR-Christian	07N 35E 34 CA	24.0
	Walla Walla C	07N 35E 35 AA	20.0
	Walla Walla C	07N 35E 35 AA	20.5
	Manuel	07N 35E 36 BA	20.0
	College Place	07N 35E 36 BD	20.4
	Richards	07N 35E 36 BD	21.0
	College Place	07N 35E 36 BD	20.0
	Stone Creek	07N 35E 36 DD	21.0
	Walla Walla Community College	07N 36E 14 CD	26.5
	Walla Walla Golf	07N 36E 17 CA	39.1
	Birdseye	07N 36E 19 BD	31.1
	Rodgers Can.	07N 36E 19 DD	28.8
	Whitman College	07N 36E 20 AC	22.0
	Walla Walla-5	07N 36E 28 DD	23.5
	Walla Walla C. Club	07N 36E 31 DA	21.0

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Walla Walla (Continued)	Walla Walla-7	07N	36E	33	BB	30.2
	Peterson	08N	31E	14	DB	24.5
	McGregor	08N	31E	34	AD	25.4
	Gluck	08N	33E	21	D	24.1
	Power	09N	32E	13	BA	22.2
	Grote	11N	35E	14	DC	28.4
	Anderson	12N	36E	26	AD	22.5
Whatcom	Mt. Baker	38N	7-8E			*
	Dorr Fumarole Field	38N	08E	17	BB	90.0
	Sherman Crater Fumaroles	38N	08E	19	BA	90-130
	Baker Hot Spring	38N	09E	20	C	42.0
Whitman	Pullman	14N	45E	5	AB	20.0
	Pullman	14N	45E	5	BB	21.0
	Colfax	16N	43E	11	AC	23.5
Yakima	Bacon Creek Spring	07N	12E	1	D	6.0
	Sharp	07N	22E	23	AB	23.4
	Mt. Adams Fumaroles	08N	10E	1		50.0
	Mabton	08N	22E	1	AC	23.0
	Flower	08N	22E	11	DA	22.0
	Soda Spring Creek Soda Spring	09N	12E	35	AB	C
	Mt. Adams	8-9N	10-11E			*
	Castile Soda Spring	09N	13E	18	DC	12.0
	Shinn	09N	21E	26	CB	28.5
	Well	09N	21E	27	DD	22.0
	Well	09N	22E	11	DA	20.3
	Grandview-4	09N	23E	22	DA	21.2
	Well	10N	17E	14	BB	20.5
	Decker-3	10N	17E	26	DD	23.8
	Well	10N	17E	23	CA	20.3
	Decker	10N	17E	27	DD	26.0
	Decker-4	10N	17E	28	AB	22.4
	Shellenberg-3	10N	17E	35	AB	21.2
	Darrow	10N	18E	5	DC	20.6
	Decker-7	10N	18E	31	CC	23.8
	Toppenish-7	10N	20E	4	CA	22.6
	Toppenish-6	10N	20E	9	AA	20.5
	Sunnyside-4	10N	22E	25	BD	20.0
	Sunnyside-7	10N	22E	25		23.9
	Sunnyside-6	10N	22E	36		24.4
	Evans	10N	23E	36	AA	26.7
	White	11N	23E	36	AC	23.0
	McCormick Meadow Soda Springs	11N	12E	24	CA	10.0
	Klickitat Meadow Soda Springs	11N	13E	4	BD	14.0
	Simcoe Soda Springs	11N	15E	9	C	20.0
	Pace	11N	16E	25	CD	25.4
	Gowdy	11N	16E	34	DB	21.4
	Mt. Adams Seed	11N	17E	1	BD	24.2

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Yakima (Continued)	Dekker	11N	17E	2	CA	25.5
	Stephenson	11N	17E	3	CA	25.2
	Stephenson	11N	17E	16	BC	31.6
	Stephenson	11N	17E	16	AD	20.8
	Siegner	11N	18E	9	CC	23.0
	Well	11N	18E	26	CA	26.4
	Wapato	11N	19E	15	AA	20.8
	Johnson	11N	20E	1	CB	28.1
	Lynch	11N	20E	1	DD	21.5
	Peters	11N	20E	6	AA	20.2
	Soost	11N	20E	13	DD	29.2
	Weatherly	11N	21E	5	AB	27.8
	Dahl	11N	21E	6	CA	29.2
	Dahl	11N	21E	6	DC	29.6
	DNR-Ramsier	11N	21E	16	CD	27.5
	DNR-Ramsier	11N	21E	16	CC	25.7
	Garretson	11N	21E	17	AA	33.1
	Clyde	11N	21E	17	AB	24.8
	Hanrahan	11N	21E	20	CB	22.2
	Ambrose Farms	11N	21E	21	AB	27.0
	Sandlin	11N	21E	22	AC	24.0
	Best	11N	21E	22	DB	25.6
	Sandlin	11N	21E	22	AC	33.4
	Sandlin-2	11N	21E	22	AC	35.2
	Gay	11N	21E	36	DB	21.5
	Well	11N	22E	21	CC	22.3
	Evans	11N	22E	26	DD	30.7
	Spauls R	11N	22E	28	CB	21.5
	Rowe Farms	11N	22E	29	CC	29.6
	De Lachapelle	11N	22E	30	AC	20.3
	De Lachapelle	11N	22E	30	BA	29.9
	Well	11N	22E	30	AC	20.3
	De Lachapelle	11N	22E	30	AC	47.8
	Ahtanum Soda Springs	12N	15E	8	C	10-14
	Shelton	12N	16E	12	CC	25.2
	White	12N	16E	15	BC	21.5
	Wiley	12N	17E	16	AA	22.2
	Hansen Fruit	12N	18E	27	AC	23.6
	Hansen Fruit	12N	18E	27	AD	29.6
	St. Clair	12N	18E	31	DD	22.2
	Mt. Adams Seed	12N	18E	32	AD	25.2
	St. Clair	12N	18E	32	CA	27.9
	Nyberg	12N	18E	33	AA	25.6
	Mt. Adams-3	12N	18E	33	AB	28.0
	Moxee	12N	19E	1	DC	30.0
	DNR Gangle	12N	19E	16	BB	22.0
	Miocene-Petro	12N	19E	17	BA	33.2
	Stepniewski	12N	19E	27	AD	20.6
	Charron	12N	20E	13	DC	27.9
	Well	12N	20E	16	BB	21.0

COUNTY	SITE***	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Yakima (Continued)	DNR81-Elephan	12N	20E	16	CA	29.2
	Logan	12N	20E	27	CC	30.4
	Logan	12N	20E	27	CB	27.5
	Estes	12N	20E	34	CC	33.1
	DNR-Cheyne Rd.	12N	20E	36	CD	29.3
	DNR-Martinez	12N	21E	16	CA	24.3
	DNR	12N	21E	16	CA	25.1
	Martinez	12N	21E	17	CA	27.8
	Griswald	12N	21E	20	CD	25.0
	Marley Orchards	12N	22E	21	DD	23.1
	Changala	12N	22E	13	CD	29.5
	Changala-2	12N	22E	13	CD	30.7
	Changala	12N	22E	29	AB	23.0
	DNR-Black RK1	12N	23E	16	DB	25.0
	Well	12N	23E	17	CD	20.3
	Carrell	13N	18E	12	AA	24.8
	Creamery Well	13N	18E	24		33.9
	Terrace Heights.	13N	19E	13	DC	24.8
	Watkins-3	13N	19E	14	AA	20.3
	Boise Well	13N	19E	19		31.1
	Country Club	13N	19E	22	CB	20.0
	Rasmussen	13N	19E	24	AA	20.0
	Sundquist	13N	20E	19	CC	22.1
	Champoux	13N	20E	20	BD	23.3
	Moxee School	13N	20E	29	BB	22.7
	Yergen	13N	20E	30	AA	24.2
	Coombs	13N	20E	33	CA	23.2
	Coombs-2	13N	20E	33	CB	30.2
	Martinez	13N	21E	34	AD	22.0
	Martinez-2	13N	21E	35	BC	22.0
	DNR81-Tieton	14N	14E	25	BC	24.2
	Goose Egg Soda Springs	14N	14E	33	C	10.0
	Mulford Spring	14N	18E	3	D	15.0
	Zirkle	14N	18E	20	AC	29.0
	Roche	14N	19E	16	CC	23.2
	U.S. Government	14N	19E	28	AB	21.0
	Indian Mineral Springs	15N	12E	10	AA	C
	Little Rattlesnake Soda Springs	15N	14E	34		C
	DNR-Wenas	15N	17E	36	AA	30.1
	Malotte Spring	16N	17E	32	D	17.0
	Bumping R. Soda Springs	17N	13E	34	BB	10.0

C - Denotes a cold spring
* - Denotes a large volcano with high heat flow and composed of recent volcanic rocks
** - Denotes recent volcanic activity in areas with high heat flow
*** - Unless identified as a spring, fumarole, or volcanics, the entries are wells.

LIST OF SCREENED GEOTHERMAL RESOURCES SITES - WASHINGTON

I. Sites in Legally-Designated Areas
Includes: National Parks, National Monuments, and Wilderness Areas

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C, or Volcanic Sites With Volcanics Older Than That of a Favorable Site
Explanation: The sites listed in this section have a maximum geothermometer of greater than 90°C listed in the literature; however, all sites with geothermometers greater than 90°C were evaluated using the chemical concentrations also listed in the literature. A most likely reservoir temperature was determined for the sites in this section of less than 90°C.

To determine favorable volcanic sites, a table was used to screen sites according to volcanic rock age and composition.

Composition	Max. Age (10^3 Years)	
Basalt	Greater than	40
Andesite	Greater than	100
Rhyolite	Greater than	1,000

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature
Exception: Excluding sites with a geothermometer of greater than or equal to 90°C.

IV. Sites Failing Population/Distance Requirements
Explanation: For direct use applications the "site" is the point of end use and the well or spring is the geothermal resource.

Screen: Sites with Population:	
1-100	Resource is on site
101-1,000	Resource is within 2 km
1,001-10,000	Resource is within 8 km
10,001-100,000	Resource is within 20 km
100,001+	Resource is within 40 km

I. Washington Sites in Legally-Designated Areas

COUNTY	SIT	LOCATION (T,R,S)			MEASURED TEMP. (°C)
Clallam	Olympic Hot Springs	29N	8W 28	B	48
	Sol Duc Hot Springs	29N	9W 32	B	50
Lewis	Ohanapecosh Hot Spring	14N	10E 4	B	50
Pierce	St. Andrews Soda Spring	15N	7E 1	C	C
	Longmire Mineral Spring	15N	8E 29	D	12-25
	Mt. Rainier	15-16N	8-9E		
	Mt. Rainier Fumaroles	16N	8E 23		52-72
Skamania	Mt. St. Helens Fumaroles	8N	5E		88-800
	Mt. St. Helens	8-9N	5E		*
	Mt. Adams (part)	8-9N	10E		*
Snohomish	Kennedy Hot Springs	30N	12E 1	A	38
	Glacier Peak	30-31N	13E		*
	Gamma Hot Springs	31N	13E 24	D	60
	Suiattle R. Mineral Seep	31N	15E 18	A	10
	Sulphur Creek Hot Springs	32N	12½E 24	B	37
Whatcom	Mt. Baker (part)	38N	7-8E		*
	Door Fumarole Field	38N	8E 17	BB	90
	Sherman Crater Fumaroles	38N	8E 19	AC	90-130
Yakima	Mt. Adams Fumaroles	8N	10E 1		50+
	Mt. Adams (part)	8-9N	10-11E		*

C - Denotes a cold spring
* - Denotes a large volcano with high heat flow and composed of recent volcanic rocks

II. Sites With Most Likely Reservoir Temperatures of Less Than 90°C or Volcanic Sites With Volcanics Older Than That of a Favorable Site - Washington

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)
Chelan	Little Wenatchee Soda Spring	27N	15E	7
	Little Wenatchee Ford Soda Spring	28N	13E	9
Cowlitz	Green River Soda Springs	10N	04E	13-25
	Pigeon Springs	07N	01E	C
Grays Harbor	Newskah Mineral Springs	16N	09W	19
King	Lester Hot Springs	20N	10E	49
	Flaming Geyser Springs	21N	06E	13
	Goldmeyer Hot Springs	23N	11E	53
	Scenic Hot Springs	26N	13E	47
Kittitas	Medicine Creek Mineral Spring	21N	17E	9
Klickitat	Klickitat Mineral Springs	04N	13E	15-29
	Blockhouse Mineral Springs	04N	15E	12
	Fish Hatchery Warm Springs	06N	13E	24
Lewis	Clear Fork Dacite	13N	9-10E	**
	Summit Creek Soda Springs	14N	11E	12
Skamania	Bonneville Hot Springs	02N	07E	36
	Rock Creek Hot Springs	03N	07E	34
	Shipherds Hot Springs	03N	08E	42
	St. Martins Hot Spring	03N	08E	53
	Little Soda Spring	04N	07E	8
	Red Mountain-Big Lava Bed	4-5N	8-9E	**
	Government Mineral Springs	05N	07E	7
	Mann Butte	05N	09E	**
	Orr Creek Warm Springs	10N	10E	22
Snohomish	Garland Mineral Springs	28N	11E	29
Yakima	Castile Soda Spring	09N	13E	12
	Klickitat Meadow Soda Spring	11N	13E	14
	Ahtanum Soda Springs	12N	15E	10-14
	Tieton Willows Drill Hole	14N	14E	24
	Goose Egg Soda Springs	14N	14E	10
	Bumping River Soda Springs	17N	13E	10

C - Denotes a cold spring
** - Denotes recent volcanic activity in areas with high heat flow.

III. Sites With Temperatures Less Than 10°C Above the Mean Ambient Air Temperature - Washington

COUNTY	SITE	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Chelan	Medicine Spring	26N	18E	13	D	8.7
Clallam	Piedmont Sulfur Spring	30N	09W	11		C
Clark	City of Vancouver Spring	02N	02E	33	C	10.0
King	Diamond Mineral Springs	21N	6E	21	C	11.0
	Skykomish Soda Springs	26N	11E	27	B	C
	Money Creek Soda Springs	26N	11E	30	C	12.0
Klickitat	Leonardo Springs	02N	13E	21	B	14.0
	Klickitat Soda Springs	04N	15E	9	C	12.0
Lewis	Vance Mineral Spring	12N	07E	22	CB	C
	Alpha Mineral Spring	13N	02E	5		C
Walla Walla	Burlingame Well	06N	35E	3	CC	20.0
	McAuslan Well	06N	35E	12	AD	21.0
	Dept. of Ecology Well	06N	35E	18	AA	20.3
	Dept. of Ecology Well	06N	35E	18	AA	21.3
	Richardson Well	06N	36E	5	CB	21.0
	Baker Well	07N	34E	25	CC	20.0
	B.P.A. Well	07N	35E	23	CB	20.0
	Clock/B.P.A. Well	07N	35E	24	CB	20.0
	Arbini Well	07N	35E	25	BD	20.0
	Columbo Well	07N	35E	25	CD	20.0
	Walla Walla C Well	07N	35E	35	AA	20.0
	Walla Walla C Well	07N	35E	35	AA	20.5
	Manuel Well	07N	35E	36	BA	20.0
	College Place Well	07N	35E	36	BD	20.4
	Richards Well	07N	35E	36	BD	21.0
	College Place Well	07N	35E	36	BD	20.0
	Stone Creek Well	07N	35E	36	DD	21.0
	Walla Walla C. Club Well	07N	36E	31	DA	21.0
Yakima	Bacon Creek Spring	07N	12E	1	D	6.0
	Soda Spring Creek Soda Spring	09N	12E	35	AB	C
	Well	09N	22E	11	DA	20.3
	Well	10N	17E	23	CA	20.3
	Sunnyside-4 Well	10N	22E	25	BD	20.0
	McCormick Meadow Soda Springs	11N	12E	24	CA	10.0
	Mulford Spring	14N	18E	3	D	15.0
	Indian Mineral Springs	15N	12E	10	AA	C
	Little Rattlesnake Soda Springs	15N	14E	34		C
	Malotte Spring	16N	17E	32	D	17.0

C - Denotes a cold spring

IV. Washington Sites Failing Population/Distance Requirements

COUNTY	SITE*	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Adams		15N 28E 4 AA	26.4
	CMST P&P	15N 28E 8 BC	20.0
	USBR	15N 28E 15 BB	24.2
	DH-4	15N 28E 30 CA	53.5
	ECBID	15N 28E 35 CD	24.4
	McKay	15N 31E 5 CA	26.4
	Lyle Bros-3	15N 31E 11 BC	20.5
	Johnson	15N 31E 19 AA	25.5
	Stelger	15N 32E 16 BD	20.0
	Hart	15N 32E 35 BC	27.6
	Tompkins	15N 33E 2 AA	25.0
	Watson	15N 34E 27 DD	20.9
	Kliphardt	16N 30E 24 BB	25.9
	Kliphardt	16N 30E 26 AA	26.2
	Andrews-2	16N 30E 27 DA	25.2
	DNR-Damon	16N 30E 36 DB	20.3
	Mike Damon	16N 30E 36 DB	25.8
	Lyle	16N 31E 15 AB	24.1
	Lyle (south)	16N 31E 15 DC	26.9
	Wholman	16N 31E 15 BB	26.2
	Phillips-12	16N 32E 11 BB	27.7
	Phillips	16N 32E 14 BA	20.7
	Phillips-11	16N 32E 14 BB	20.0
	Phillips-17	16N 32E 15 BB	33.4
	Phillips	16N 32E 20 CC	29.2
	Phillips-10	16N 32E 21 BC	27.4
	Phillips	16N 32E 23 BB	21.6
	Phillips-2	16N 32E 25 BB	28.7
	Phillips-16	16N 32E 25 CC	31.0
	Phillips-C-34	16N 32E 34 BC	43.4
	Phillips-9	16N 32E 35 BB	24.0
	Baumann	16N 35E 31 DC	22.4
	Phillips C-12	17N 31E 12 BB	27.8
	DNR	17N 32E 14 CB	23.2
	Benge/Connell	17N 37E 27 BB	21.9
	Hutterites	18N 31E 18 BA	21.8
	Phillips C-33	18N 31E 33 BB	30.0
	Kagele	19N 31E 24 AC	20.1
	S&K Farms	19N 32E 24 DB	20.6
	J&M Farms	19N 32E 24 CC	31.5
	Hoefel	19N 33E 8 DC	20.3
	Hoefel	19N 33E 8 DC	41.0
	Kagele	19N 34E 20 AB	22.5
	Heinemann-2	19N 36E 34 CC	20.7
	Well	19N 38E 13 BD	21.1
	Weber	20N 34E 2 DC	20.9
	Hardung	20N 35E 17 BB	20.9
	Ahern	20N 35E 24 BB	20.5

COUNTY	SITE*	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Benton	Sperry	04N	24E	3	AB	20.6
	Powers	05N	26E	5	BB	26.3
	Engineers	05N	28E	6	DD	21.5
	Columbia River	06N	24E	22	AB	22.5
	Craig	06N	26E	15	CB	24.2
	Blair	06N	30E	12	DC	21.1
	Irrigro	06N	30E	19	CC	20.5
	Horrigan Farms	07N	24E	8	BB	24.1
	DOE Patterson	07N	25E	36	CC	22.5
	DOE Patterson	07N	25E	36	CC	30.3
	DNR-Baker	07N	25E	36	CD	21.8
	DOE	07N	25E	36	CC	22.7
	Moon	07N	26E	5	AB	22.1
	DOE H Heaven	07N	27E	36	AA	26.3
	DNR-Gould	08N	25E	36	AB	25.9
	Prosser Exp.	09N	25E	6	AB	27.8
	DNR-Anderson	10N	24E	36	BD	29.8
	Nakamura	10N	25E	25	BC	20.6
	J&R Orchard	10N	25E	33	CC	21.8
	VO-SOC1	11N	26E	20	CC	40.1
	U.S. Government	11N	26E	34	DD	24.0
	Tramel	12N	24E	5	AA	20.4
	Tramel	12N	24E	5	AA	23.0
	Roberts Bros.	12N	24E	20	CC	26.0
	U.S. Government	12N	26E	4	CC	21.4
	U.S. Government	12N	26E	7	AB	20.7
	U.S. Government	12N	26E	7	DC	20.4
	U.S. Government	12N	26E	8	CD	21.2
	U.S. Government	12N	26E	12	AD	21.0
	U.S. Government	12N	26E	14	BB	21.1
	U.S. Government	12N	26E	15	BA	21.7
	U.S. Government	12N	26E	18	BC	20.5
	U.S. Government	12N	26E	18	AC	20.8
	U.S. Government	12N	27E	16	CB	20.5
	U.S. Government	13N	24E	25	BC	24.2
	Meeker	13N	24E	26	AC	20.0
	U.S. Government	13N	24E	36	BB	24.0
	U.S. Government	13N	25E	1	CC	23.0
	Well	13N	25E	11	AD	39.1
	McGee	13N	25E	30	AC	26.8
	DDH-1	13N	26E	35	AA	21.9
	ARH DC-1	13N	26E	35	DB	75.0
	Hanford DDH-1	13N	26E	35	AA	24.8
	ARH DC-1	13N	26E	35	AA	70.0
	Hanford DC-6	13N	27E	26	AC	60.2
	Well	14N	26E	14	CB	32.5
	Well	14N	26E	28	AC	20.7
	Hanford	14N	26E	28	DA	25.0
	Hanford	14N	26E	28	CD	25.5
	Hanford	14N	26E	29	DD	25.4
	Hanford	14N	26E	33	AC	27.0

COUNTY	SITE*	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Columbia	Ferrell	12N	38E	1	BC	22.0
		13N	38E	26	BC	20.0
Douglas	Welch	20N	22E	12	AB	22.0
	Pixlee	23N	26E	20	BB	29.3
Franklin	Nakamura	09N	31E	7	BC	24.6
	Nakamura	11N	31E	21	AD	24.2
	Well	12N	28E	8	AB	23.4
	U.S.B.R.	13N	28E	13	CC	27.6
	Bailie	13N	29E	13	DB	22.6
	Cockrane	13N	34E	30	CB	32.2
	U.S. Government	14N	29E	9	AA	22.3
	Othello A.F.B.	14N	29E	9	AA	22.2
	Rathburn	14N	31E	8	CB	46.8
	Hart	14N	32E	2	CD	27.2
	Hart	14N	32E	13	BC	25.6
	Heider	14N	33E	21	CC	27.3
	Gillis	14N	36E	19	CC	23.0
Grant	U.S. Army	14N	25E	1	BB	27.5
	Hanford 93-93	14N	25E	1	BB	25.6
	U.S. Government	14N	25E	21	AB	22.0
	U.S. Army	14N	27E	24	BA	30.0
	DH-5	15N	24E	25	CD	74.0
	Hanford DH-5	15N	24E	25	CD	72.7
	AEC	15N	27E	34	CA	21.5
	U.S. Government	16N	24E	1	AC	23.5
	U.S.A.F.	16N	24E	1	AC	24.5
	METRO	17N	25E	1	BD	25.3
	Well	17N	30E	1	AC	23.0
	U.S. Army	17N	30E	33	DB	22.2
	U.S. Army	17N	30E	33	DB	23.5
	Washington	18N	25E	15	BC	25.6
	DOE-George	18N	25E	15	BC	22.4
	DOE-George	18N	25E	15	BC	29.3
	METRO M.-11A	18N	25E	23	DA	21.2
	Farm Man	18N	25E	27	CC	21.2
	Bradshaw	18N	25E	28	AB	22.4
	METRO M.-20	18N	26E	31	DB	22.5
	Shinn	18N	26E	35	C	23.2
	Franz-2	20N	30E	23	AA	21.5
	Franz	20N	30E	23	BC	34.8
	King	22N	30E	26	AC	25.0
	Schaffer	23N	28E	27	BC	22.8
	Well	25N	28E	24	AC	29.2
	Dormaier	25N	28E	25	AB	23.0
Kittitas	Clerf	18N	20E	27	AA	19.3

COUNTY	SITE*	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Klickitat	Gas-Ice Corp.	04N 13E 24 AD	27.2
	DNR81-Klick	04N 13E 24 BC	20.1
	Case	05N 15E 25 DB	19.7
	Berk Bros.	05N 20E 27 AB	22.8
	Berk	05N 20E 27 AB	23.1
	DOE	05N 21E 16 CA	27.3
	Matsen	05N 22E 27 AA	28.2
	Powers	05N 23E 29 BB	26.2
	McBride	05N 23E 29 BB	25.5
	Smith	06N 23E 11 CD	22.0
	Smith	06N 23E 11 DC	21.0
	Andrews	06N 23E 15 AD	25.2
	Andrews	06N 23E 22 DA	23.0
	DNR-Mercer N	06N 23E 36 BD	20.8
Lewis	SU-8	12N 01W 7 AA	25.2
	SU-14	12N 01W 8 CC	25.6
	SU-37	12N 01W 8 CC	24.7
	SU-11	12N 01W 8 DA	21.3
	SU-12	12N 01W 8 DA	25.7
	Longview-10	12N 01W 17	30.0
	SU-4	12N 01W 9 CC	28.8
	SU-902	12N 01W 17 AD	31.2
	Packwood Hot Spring	13N 09E 32	38.0
Lincoln	Basalt Explr.	21N 31E 10 CB	65.8
	Basalt Explr.	21N 31E 10 CB	57.5
	Basalt Explr.	21N 31E 10 CB	64.0
	Schell	21N 31E 10 CB	30.4
	DOE Basdalt Ex	21N 31E 10 CB	28.9
	Bates	21N 31E 22 BC	19.8
	Sahible	21N 31E 25 AB	28.3
	Kissler	21N 31E 30 DD	22.8
	Kissler	21N 31E 32 BB	21.1
	Hardung	21N 34E 33 BA	24.9
	Weishaar	23N 32E 4 DA	28.7
	Weishaar	23N 32E 17 AC	21.2
	Zagelow	23N 32E 10 DA	21.6
	Zagelow	23N 33E 14 BC	19.2
	USGS Almira	24N 31E 16 BC	20.1
	USGS Almira	24N 31E 16 BC	20.0
	DOE	24N 31E 16 BC	21.8
	Schmierer	24N 33E 23 CD	25.9
	Nealey	24N 34E 30 CD	21.0
	USGS Davenport	24N 36E 16 AA	21.3
	DOE	24N 36E 16 AA	21.9
	GEIB	26N 32E 10 AD	19.2
	Rexcon SF-15	27N 37E 22 CD	19.5
	Taylor	27N 37E 26 AA	23.8

COUNTY	SITE*	LOCATION (T,R,S)				MEASURED TEMP. (°C)
Skamania	DNR81-Carson	03N	08E	21	BD	27.8
Walla Walla	Warm Spring Canyon Warm Spring	06N	32E	2	D	22.0
	Fulgham	06N	33E	1	DB	31.8
	Chvatel	06N	34E	6	AB	34.4
	Gilbert-Merry	06N	34E	7	CD	40.7
	Byerly	07N	32E	36	DC	24.0
	Taggart	07N	33E	24	DC	23.2
	McDole	07N	33E	31	DB	27.7
	Peterson	08N	31E	14	DB	24.5
	McGregor	08N	31E	34	AD	25.4
	Gluck	08N	33E	21	D	24.1
	Power	09N	32E	13	BA	22.2
	Grote	11N	35E	14	DC	28.4
	Anderson	12N	36E	26	AD	22.5
Yakima	Sharp	07N	22E	23	AB	23.4
	Flower	08N	22E	11	DA	22.0
	Shinn	09N	21E	26	CB	28.5
	Well	09N	21E	27	DD	22.0
	Well	10N	17E	14	BB	20.5
	Decker-3	10N	17E	26	DD	23.8
	Decker	10N	17E	27	DD	26.0
	Decker-4	10N	17E	28	AB	22.4
	Shellenberg-3	10N	17E	35	AB	21.2
	Darrow	10N	18E	5	DC	20.6
	Decker-7	10N	18E	31	CC	23.8
	Simcoe Soda Springs	11N	15E	9	C	20.0
	Pace	11N	16E	25	CD	25.4
	Gowdy	11N	16E	34	DB	21.4
	Stephenson	11N	17E	16	BC	31.6
	Stephenson	11N	17E	16	AD	20.8
	Weatherly	11N	21E	5	AB	27.8
	Dahl	11N	21E	6	CA	29.2
	Dahl	11N	21E	6	DC	29.6
	DNR-Ramsier	11N	21E	16	CD	27.5
	DNR-Ramsier	11N	21E	16	CC	25.7
	Garretson	11N	21E	17	AA	33.1
	Clyde	11N	21E	17	AB	24.8
	Sandlin	11N	21E	22	AC	24.0
	Best	11N	21E	22	DB	25.6
	Sandlin	11N	21E	22	AC	33.4
	Sandlin-2	11N	21E	22	AC	35.2
	Well	11N	22E	21	CC	22.3
	Evans	11N	22E	26	DD	30.7
	Spauls R	11N	22E	28	CB	21.5
	Rowe Farms	11N	22E	29	CC	29.6
	De Lachapelle	11N	22E	30	AC	20.3
	De Lachapelle	11N	22E	30	BA	29.9
	De Lachapelle	11N	22E	30	AC	47.8

COUNTY	SITE*	LOCATION (T,R,S)	MEASURED TEMP. (°C)
Yakima (Continued)	White	12N 16E 15 BC	21.5
	DNR-Martinez	12N 21E 16 CA	24.3
	DNR	12N 21E 16 CA	25.1
	Martinez	12N 21E 17 CA	27.8
	Griswald	12N 21E 20 CD	25.0
	Marley Orchards	12N 22E 21 DD	23.1
	Changala	12N 22E 13 CD	29.5
	Changala-2	12N 22E 13 CD	30.7
	Changala	12N 22E 29 AB	23.0
	DNR-Black RK1	12N 23E 16 DB	25.0
	Well	12N 23E 17 CD	20.3
	Martinez	13N 21E 34 AD	22.0
	Martinez-2	13N 21E 35 BC	22.0
	DNR-Wenas	15N 17E 36 AA	30.1

* Unless identified as a spring, all entries are wells.

I. Electrical Generation Sites

An electrical generation site is a well or spring with a geothermometer of greater than or equal to 90°C, or an area displaying recent volcanic flows and high heat flow. These sites have been screened.

II. Direct Utilization Sites

A direct utilization site is a point of end use, such as a city or town. A geothermal well or spring is considered the resource. These sites have been screened.

I. Electrical Generation Sites - Washington

COUNTY	SITE	LOCATION (T,R,)		MEASURED TEMP. (°C)	MAX. GEOTHERM (°C)
Skamania	Puny Creek Basalt	05N	06E	**	**
Whatcom	Mt. Baker (part)	38N	7-8E	*	*
	Baker Hot Spring	38N	09E	42	170
Yakima	Mt. Adams (part)	8-9N	11E	*	*

* Denotes a large volcano with high heat flow and composed of recent volcanic rocks.
** Denotes recent volcanic activity in areas with high heat flow.

II. Direct Utilization
Sites - Washington

COUNTY	SITE	LOCATION (T,R,S)				POP.	MEASURED TEMP. (°C)
Adams	Othello	15N	29E	3	C	4,570	29.0
	Cunningham	15N	32E	4	A	Uninc	21.8
	Washtucna	15N	36E	28	C	280	25.4
	Lind	17N	33E	12	C	594	21.0
	Ritzville	19N	38E	23	B	1,860	20.4
Asotin	Clarkston	11N	46E	21	D	6,700	26.2
Benton	Prosser	08N	24E	2	A	3,788	25.2
	Kennewick	08N	29E	1	A	29,810	23.0
	Benton City	09N	27E	19	D	1,900	23.3
	West Richland	09N	28E	6	A	2,641	26.6
	Richland	10N	28E	11	B	33,550	39.7
Chelan	Wenatchee	22N	20E	3	C	17,150	35.7
Douglas	East Wenatchee	22N	20E	3	C	1,605	35.7
Franklin	Pasco	09N	30E	29	D	19,100	21.0
	Connell	14N	32E	31	B	1,840	29.4
Garfield	Pomeroy	12N	42E	31	C	1,675	23.0
Grant	Warden	17N	30E	15	B	1,463	23.0
	Moses Lake	19N	28E	23	B	10,300	23.7
	Ephrata	21N	26E	15	B	5,440	30.0
	Soap Lake	22N	27E	19	B	1,240	27.0
Kittitas	Ellensburg	18N	18E	35	C	11,550	28.4
Klickitat	Wahkiacus	04N	14E	19	B	Uninc.	22.8
Lincoln	Odessa	21N	33E	5	C	1,020	24.1
	Davenport	25N	37E	21	B	1,580	24.0
	Reardon	25N	39E	15	B	485	20.0
Skamania	North Bonneville	02N	07E	16	D	427	35.5
	Stevenson	03N	07E	36	D	1,160	34.0
	St. Martin Hot Spring Resort	03N	08E	21	D	5-30	53.0
Spokane	Cheney	23N	41E	13	B	7,600	31.9
Walla Walla	College Place	07N	35E	35	A	5,675	24.0
	Walla Walla	07N	36E	29	A	25,600	39.1
Whitman	Pullman	14N	45E	5	BB	23,000	21.0
	Colfax	16N	43E	14	B	2,820	23.5

COUNTY	SITE	LOCATION (T,R,S)	POP.	MEASURED TEMP. (°C)
Yakima	Mabton	09N 23E 31 C	1,235	23.0
	Grandview	09N 23E 23 B	6,300	21.2
	Toppenish	10N 20E 4 C	6,575	22.6
	Sunnyside	10N 22E 25 B	9,450	24.4
	Harrah	11N 18E 34 D	345	26.4
	Zillah	11N 20E 36 B	1,685	29.2
	Granger	11N 21E 21 A	1,810	21.5
	Yakima Area	13N 18E 24 A	56,885	33.9

EXHIBIT II

A Summary of Resource Assessment Results

GEOTHERMAL ELECTRIC GENERATION SITES - IDAHO

SITE	MOST LIKELY TEMP. C°	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Krigbaum HS	97	2.0	1.5	3.3	8.78E+17	0
White Licks HS	145	2.0	1.5	3.3	1.30E+18	2
Guyer HS	88	2.0	1.5	3.3	8.05E+17	0
Bonneville HS	94	2.0	1.5	3.3	9.38E+17	0
Deer HS	139	2.0	1.5	3.3	1.22E+18	2
Big Southern Butte				100.0	0.00E+00	0
Barron's HS	95	2.0	1.5	3.3	8.72E+17	0
Magic Reservoir	140	2.0	1.5	3.3	1.14E+18	2
Worswick HS	90	2.0	1.5	3.3	7.77E+17	0
Blackfoot Lava Field	230	25.0	n/a	133.0	2.40E+20	1715
Raft River	147	15.0	1.0	20.6	7.85E+18	12
Sunbeam HS	94	2.0	1.5	3.3	8.13E+17	0
Latty HS	102	2.0	1.5	3.3	7.92E+17	1
Battle Creek HS	116	2.0	1.7	3.1	8.93E+17	1
Ben Meek Well	97	2.0	1.7	3.1	7.66E+17	0
Maple Grove HS	106	2.0	1.5	3.3	8.60E+17	1
Squaw Creek HS	124	2.0	1.7	3.1	9.44E+17	2
Island Park Caldera	230	100.0	n/a	14150.0	1.69E+22	158378
Roystone HS	135	2.0	1.5	3.3	1.12E+18	2
White Arrow	115	3.0	1.5	5.8	1.73E+18	1
Riggins HS	98	2.0	1.5	3.3	7.90E+17	0
Big Creek HS	159	2.0	1.5	3.3	1.40E+18	23
Owl Creek HS	123	2.0	1.5	3.3	1.08E+18	1
Sharkey HS	107	2.0	1.5	3.3	9.69E+17	1
Rexburg Caldera	230	800.0	n/a	10500.0	8.40E+21	102873
Indian Creek HS	121	2.0	1.5	3.3	9.68E+17	1
Murphy HS	99	2.0	1.5	3.3	8.80E+17	1
Boiling Springs	100	2.0	1.5	3.3	8.54E+17	0
Cabarton HS	99	2.0	1.5	3.3	8.97E+17	0
Vulcan HS	97	2.0	1.5	3.3	9.17E+17	0
Cove Creek/Crane Creek HS	163	15.0	1.5	38.9	1.60E+19	179

GEOTHERMAL ELECTRIC GENERATION SITES - MONTANA

SITE	MOST LIKELY TEMP. C°	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Jackson	148	2.0	1.5	3.3	1.08E+18	2
Gregson (Fairmont)	126	2.0	1.5	3.3	9.34E+17	1
Boulder	136	2.0	1.5	3.3	1.18E+18	2
Broadwater		2.0	1.5	3.3	8.09E+17	0
Ennis		2.0	1.5	3.3	1.11E+18	2
Morris		2.0	1.5	3.3	9.07E+17	1
Silver Star		2.0	1.5	3.3	1.13E+18	2
Marysville		6.0	1.5	14.0	4.42E+18	4

GEOTHERMAL ELECTRIC GENERATION SITES - OREGON

SITE	MOST LIKELY TEMP. C°	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Kropp HS	100	2.0	1.5	3.3	8.01E+17	0
Austin HS	90	2.0	1.5	3.3	8.20E+17	0
Mt. Hood	120	30.0	0.4	32.8	1.14E+19	5
Bearhallow Butte	230	8.0		43.0	4.10E+19	610
China Hat-East Butte				0.0	0.00E+00	0
Frederick Butte		32.0		125.0	0.00E+00	0
Melvin-Three Creek Buttes	230	10.0		55.0	7.60E+19	1104
Newberry Volcano	265	45.0	1.5	109.0	7.60E+19	1557
Quartz Mountain				0.0	0.00E+00	0
Shukash Basin				0.0	0.00E+00	0
Umpqua HS	108	2.0	1.5	3.3	9.64E+17	1
Blue Mountain HS	99	2.0	1.5	3.3	9.00E+17	0
Heberg HS	92	2.0	1.5	3.3	8.68E+17	0
Alvord HS	164	2.0	1.7	4.7	2.19E+18	28
Borax Lake HS	176	4.0	1.7	7.8	3.86E+18	66
Crane HS	124	2.0	1.7	3.1	9.41E+17	2
Diamond Craters				0.0	0.00E+00	
Mickey HS	227	4.0	1.7	12.0	6.72E+18	110
O.J. Thomas Hell	102	2.0	1.7	3.1	8.14E+17	1
Trout Creek Area	143	2.0	1.7	3.1	1.24E+18	3
Mt. McLoughlin Area	190	1050.0	1.3	1066.7	5.04E+20	14078
Rustler Peak				0.0	0.00E+00	0
Cappy-Burn Butte Area	230	8.0		47.0	1.30E+19	378
Crater Lake Area	190	2630.0	1.3	3362.5	1.63E+21	36241
Klamath Falls Area	180	21.0	1.7	28.8	1.27E+19	362
Klamath Hills Area	180	17.0	1.7	28.8	1.31E+19	293
Olene Gap HS	180	1.2	1.7	6.7	2.99E+18	21

GEOTHERMAL ELECTRIC GENERATION SITES - OREGON

SITE	MOST LIKELY TEMP. C°	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Barry Ranch HS	139	0.8	1.7	10.0	3.54E+18	1
Cougar Peak Area				0.0	0.00E+00	0
Crump Geyser	173	4.0	1.7	6.8	3.08E+18	63
Devils Garden Area				0.0	0.00E+00	0
Fischer HS	123	2.0	1.7	3.1	1.09E+18	1
Four Craters Lava Field				0.0	0.00E+00	0
Glass Buttes	230	21.0	0.8	21.8	1.34E+19	278
Hallinan HS	136	2.0	1.7	3.1	1.10E+18	2
Lakeview Area	143	6.0	1.7	13.8	5.08E+16	8
Squaw Ridge Field				0.0	0.00E+00	0
Summer Lake HS	127	5.0	1.7	8.9	3.19E+18	4
Hart Peak Caldera	230	40.0		217.0	4.00E+18	116
Belknap HS	108	2.0	1.5	3.3	9.38E+17	1
Bigelow HS	89	2.0	1.5	3.3	7.97E+17	0
Foley HS	106	2.0	1.5	3.3	8.21E+17	1
McCredie HS	96	2.0	1.5	3.3	7.89E+17	0
Hall Creek HS	92	2.0	1.5	3.3	7.47E+17	0
Generic HC Fault System	190	2.0	1.3	2.1	1.02E+18	27
Beulah HS	85	2.0	1.7	3.1	8.76E+17	0
Jackies Butte Field				0.0	0.00E+00	0
Jordan Craters Field				0.0	0.00E+00	0
Little Valley HS	118	2.0	1.7	3.1	8.76E+17	1
Luce HS	116	2.0	1.7	3.1	9.32E+17	1
McDermitt Area	90	2.0	1.7	3.1	6.97E+17	0
Mitchell Butte HS	90	2.0	1.7	3.1	6.93E+17	0
Heal HS	181	2.0	1.7	3.1	1.50E+18	34
Vale HS	152	41.0	0.5	34.9	1.36E+19	130

GEOTHERMAL ELECTRIC GENERATION SITES - OREGON

SITE	MOST LIKELY TEMP. C^o	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Breitenbush HS	102	2.0	1.5	3.3	8.99E+17	1
Medical HS	97	2.0	1.5	3.3	8.01E+17	0
Kahneeta HS	147	2.0	1.5	3.3	1.14E+18	2

GEOTHERMAL ELECTRIC GENERATION SITES - WASHINGTON

SITE	MOST LIKELY TEMP. C^o	MOST LIKELY RESERVOIR AREA Km^2	MOST LIKELY RESERVOIR THICKNESS Km	RESERVOIR VOLUME Km^3	RES. THERMAL ENERGY $J \times 10^{18}$	BEST ELECTRICAL ENERGY MWe
Puny Creek Basalt	(?)			0.0	0.00E+00	0 (?)
Mt. Baker				0.0	0.00E+00	0
Baker Hot Spring	139	2.0	1.5	3.3	1.16E+18	2
Mt. Adams (Part)	(?)			0.0	0.00E+00	0 (?)

KEY TO UNITS

Temperature = ^{o}C

Area = km^2

Thickness = km

Volume = km^3

DIRECT USE GEOTHERMAL RESOURCE SITES - IDAHO

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Boise/Garden City	77	50.0	0.1	6.6	110
Eagle	40	6.0	0.1	0.8	5
Meridian	21			1.0	0
Western Snake River Plain	30	550.0	0.1	66.1	35
Council	22			1.0	1
Chubbuck/Pocatello	35	9.0	0.1	1.1	5
Lava Hot Springs	51			1.0	14
Hailey	83			1.0	28
Ketchum	88			1.0	30
Idaho City	63			1.0	19
Idaho Falls/Ammon	20			1.0	1
Butte City	52			1.0	15
Fairfield	31			1.0	6
Nampa/Caldwell	49	140.0	0.2	25.7	65
Parma	20			1.0	0
Soda Springs	31			1.0	5
Challis	49			1.0	13
Stanley	43			1.0	12
Glenns Ferry	63	40.0	0.1	4.3	46
Mtn. Home	21			1.0	0
Mtn. Home AFB	20			1.0	0
Preston	125			1.0	44
Ashton	91			1.0	31
Emmett	20			1.0	0
Rexburg	30			1.0	6
Paul	22			1.0	1
Malad City	29			1.0	4
Grand View	40	750.0	0.1	87.5	123
Homedale	21			1.0	0
Payette	20			1.0	0
American Falls	31	8.0	0.1	0.9	4
Buhl	45	50.0	0.1	6.8	48

DIRECT USE GEOTHERMAL RESOURCE SITES - IDAHO

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Filer	31			1.0	5
Hansen/Kimberly	20			1.0	0
Twin Falls	38			1.0	7
Cascade	70	12.0	0.1	1.4	25

DIRECT USE GEOTHERMAL RESOURCE SITES - MONTANA

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Polaris	56			1.0	18
Townsend	24			1.0	3
Anaconda	36			1.0	9
Warm Springs	80			1.0	27
Bozeman	75			1.0	24
Clancy	82			1.0	27
Whitewall	86			1.0	29
Hot Springs	59			1.0	17
White Sulpher Springs	73			1.0	24
Lolo	60			1.0	18
Emmigrant	54			1.0	16
Gardiner	71			1.0	23
Liningston	30			1.0	6
Avon	26			1.0	4
Deer Lodge (prison)	34			1.0	8
Garrison	27			1.0	5
Grantsdale	82			1.0	27
Sula	49			1.0	14
Camas	85			1.0	28
Paradise	66			1.0	20

DIRECT USE GEOTHERMAL RESOURCE SITES - OREGON

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Baker	52			1.0	16
Haines	65			1.0	21
Huntington Area	24			1.0	3
North Powder	43			1.0	11
Government Camp	38	28.3	0.9	31.2	25
Arlington	22			1.0	1
Ritter Hot Springs	68			1.0	21
Burns Area	60	12.0	0.1	1.6	41
Parkdale	97			1.0	32
Ashland	52	3.6	0.1	0.4	25
Klamath Falls Area	60	30.0	0.1	3.7	48
Lakeview Area	62	16.0	0.1	3.0	68
Paisley Area	43	13.0	0.1	1.6	40
Oakridge Area	29			1.0	4
Adrian Area	57			1.0	15
Jordan Valley	50			1,0	13
Ontario Area	25			1.0	2
Vale HS Area	29	4.0	0.1	0.5	1
Boardman Area	26			1.0	2
Heppner Area	21			1.0	0
Irrigon Area	20			1.0	0
Lexington Area	20			1.0	0
Troutdale	50			1.0	12
Athena	21			1.0	0
Echo	22			1.0	1

DIRECT USE GEOTHERMAL RESOURCE SITES - OREGON

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Hermiston	21			1.0	0
Milton-Freewater	20			1.0	0
Pendelton	20			1.0	0
Pilot Rock	20			1.0	0
Stanfield	22			1.0	1
Umatilla	22			1.0	1
Weston	21			1.0	0
Cove Area	45	5.0	0.1	0.6	5
Imbler Area	68	88.0	0.1	9.9	102
La Grande Area	90	12.0	0.1	1.6	32
Union Area	80	6.0	0.1	0.9	14
Kahneeta Hot Springs	52			1.0	13
Rajneeshpurem	20			1.0	0
The Dalles	20			1.0	0
Spray City Well	33			1.0	6

DIRECT USE GEOTHERMAL RESOURCE SITES - WASHINGTON

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Connell-Cunningham	41	700.0	0.2	105.0	73
Lino	21			1.0	1
Othello	54	300.0	0.2	75.6	87
Ritzville	20			1.0	0
Washtucna	25			1.0	2
Clarkston	23			1.0	1
Benton City	22			1.0	1
Kennewick	23			1.0	1
Prosser	25			1.0	2
Richland	21			1.0	0
West Richland	21			1.0	0
Wenatchee/East Wenatchee	20			1.0	0
Pasco	21			1.0	0
Pomeroy	23			1.0	1
Ephrata	30	300.0	0.2	75.6	26
Moses Lake	35	1000.0	0.1	116.7	60
Soap Lake	27		0.1	1.0	3
Warden	23			1.0	1
Ellensburg	21			1.0	1
Wahkiacus	29			1.0	4
Davenport	24			1.0	3
Odessa	35	300.0	0.1	33.1	40
Reardon					
N. Bonneville	36			1.0	7
Stevenson	34			1.0	6
St. Martin's HS Resort	42			1.0	9
Cheney	29			1.0	4
Walla Walla/College Place	41	350.0	0.1	36.9	57
Colfax	24			1.0	2
Pullman	21			1.0	2
Grandview	23			1.0	1

DIRECT USE GEOTHERMAL RESOURCE SITES - WASHINGTON

SITE	MOST LIKELY RESERVOIR TEMPERATURE	MOST LIKELY RESERVOIR AREA	MOST LIKELY RESERVOIR THICKNESS	RESERVOIR VOLUME	BEST MWth
Granger	20			1.0	0
Harrah	26			1.0	2
Mabton	23			1.0	1
Sunnyside	20			1.0	0
Toppenish	21			1.0	0
Yakima	36	1000.0	0.1	108.9	62
Zillah	27			1.0	3